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IBIS

Quarterly Report

Analysis of Cost:
CVD Diamond Deposition

Contract Number: N00014-93-C2044

IBIS Associates, Inc.
55 William Street
Suite 220
Wellesley, MA 02181

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3rd Quarter 1993

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Executive Summary

IBIS Associates has updated its predictive spreadsheet models of the DC arcjet and microwave chemical vapor deposition (CVD) diamond technologies. This report presents the results obtained with the new models and revised sets of baseline inputs for diamond heat sink manufacture. The cost of producing 1,000 polished diamond wafers, 1 mm thick, is estimated in the long run to be $23.70 per square centimeter by the DC arcjet deposition technology (six inch diameter), and $8.49 per square centimeter by the microwave deposition technology (sixteen inch diameter).

Fifty-one percent of the DC arcjet cost is due to the deposition step, which consumes process gases and is capital intensive. Overall, the material cost of 31.2% and labor cost of 30.2% are significant factors in the total cost.

Eighty-seven percent of the microwave cost is due to the deposition step, which is capital intensive. Overall, the equipment cost of 37.9% and the material, utility and maintenance costs each at about 15.5% are significant factors in the total cost.

The major revision of the DC Arcjet Model is the inclusion of the kinetic theory of DC arcjet deposition into the model. According to the model based on this theory, the key factors driving the cost of thermal management diamond produced by the DC arcjet technology are the gas temperature, the power of the reactor, and the substrate diameter. It is shown that maximizing the gas temperature is critical to reducing the cost of the diamond wafer due to its dramatic effect on growth rate.

The major revision of the Microwave Model is the incorporation of similar theory of deposition kinetics, adapted to the typical conditions of microwave deposition. According to the model, the key factor driving the cost of thermal management diamond produced by the microwave technology is the power of the reactor. The reactor power has such a strong effect on cost because it affects both the linear growth rate and the plasma ball diameter. There are two inputs to the diffusion model which have a strong effect on the deposition cost. Research in the area of those inputs, the surface recombination of hydrogen at the substrate and the plasma ball skew or shape factor, has not advanced far enough to predict these input values reliably. The values for these inputs in the current version of the model were reported to IBIS as typical values by Professor David Goodwin at the California Institute of Technology.

To be investigated further are the relationships between diamond growth rate and process yield for both the DC arcjet and microwave technologies. It is expected that as the growth rate increases, the yield decreases; yet a specific relation between these factors is unknown. Similarly, the relationship between substrate diameter and yield requires further investigation, due to the known complications with the increase of this parameter. Lastly, expert approval of the models is continually in progress.

Modeling Progress

The seven steps for the fabrication of diamond film are Surface Preparation, Deposition, Etching, Laser Trimming, Lapping, Microscopic Inspection, and Thermal Conductivity Inspection. The flowchart for the process is shown in Figure 1, and descriptions for the processes that existed before this quarter can be obtained from previous quarterly reports.

The progress of the CVD diamond thin film models has involved both deposition improvements and the addition of the secondary operation of laser trimming. The changes to the deposition steps are described later in this report, and the laser trimming operation is described in the following section.

Laser Trimming

During the deposition process, the gas plasma deposits diamond around the edges of the deposition substrate, causing low quality diamond to form on the periphery of the desired area. Through laser trimming, the final shape of the diamond wafer can be cut, removing excess material. This process is usually performed one wafer at a time.

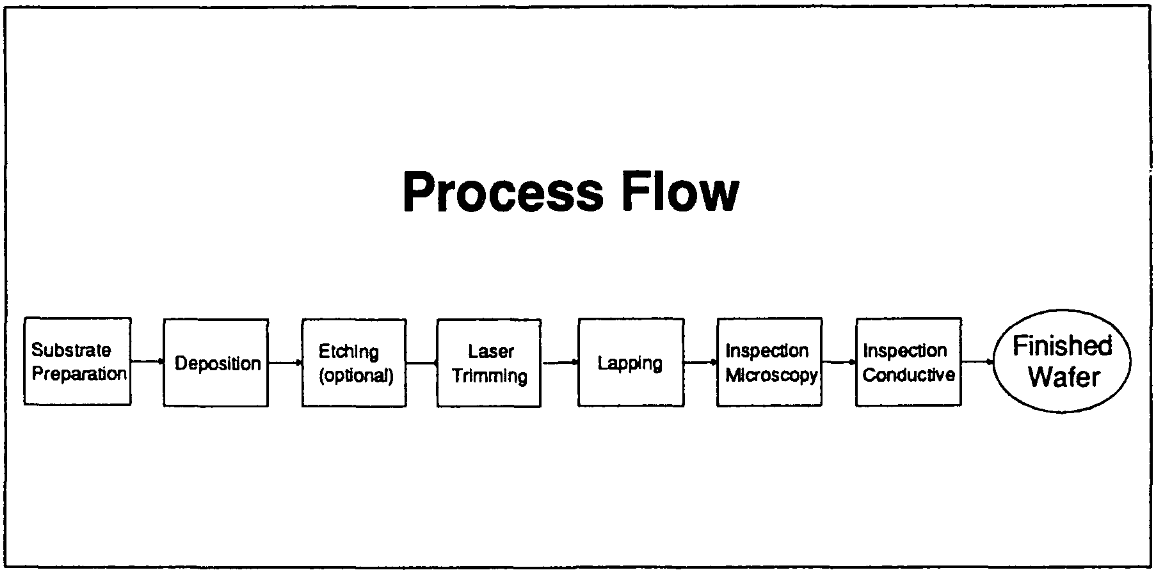


Figure 1

DC Arcjet Model

The progress of the DC Arcjet Model, as stated above, has involved the incorporation of deposition theory and a laser trimming step into the cost model. The incorporation of the theory has been accomplished with the help of Professor David Goodwin of Caltech and Dr. Richard Woodin of Technion. Subsequent progress by IBIS has been the conducting of analyses with the new model and soliciting expert review for its approval. A printout of the model is included in Appendix A, and the new deposition operation in the model are described in the following section.

Description of the DC Arcjet Deposition Theory

A theory of the physics and chemistry involved in the chemical vapor deposition of diamond by means of convective flows has been developed by Professor David Goodwin and Dr. Richard L. Woodin. With the help of Professor Goodwin and Dr. Woodin, IBIS Associates has successfully incorporated this theory into a Technical Cost Model for the manufacture of CVD diamond using the DC arcjet technology.

Figure 2 shows the two steps involved in modeling the linear growth rate of diamond, the basis of the theory being that the linear growth rate of diamond is proportional to the square of the concentration of atomic hydrogen at the growth surface. First, an energy balance from the input parameters determines the concentration of atomic hydrogen in the gas jet, then a boundary layer calculation leads to the determination of atomic hydrogen concentration at the substrate.

An energy balance of the gas jet physical and chemical reactions determines an equilibrium value for either the inlet gas temperature or the inlet gas volumetric flow rate, as well as the mole fraction of atomic hydrogen in this hot gas stream. The input side of the energy balance contains the power that is imparted to the gas by the DC arc power source. The output side of the energy balance contains the mean specific enthalpy of the gas mixture plus the kinetic energy of the gas stream.

The mole fractions in the gas mixture are calculated from gas flow rates (an input), the pressure inside the reactor (an input), the heat, entropy and free energy of reaction for the conversion of molecular hydrogen to atomic hydrogen. The heat, entropy and free energy of the reaction are determined from the temperature of the gas mix, the ideal gas constant and NASA enthalpy constants.

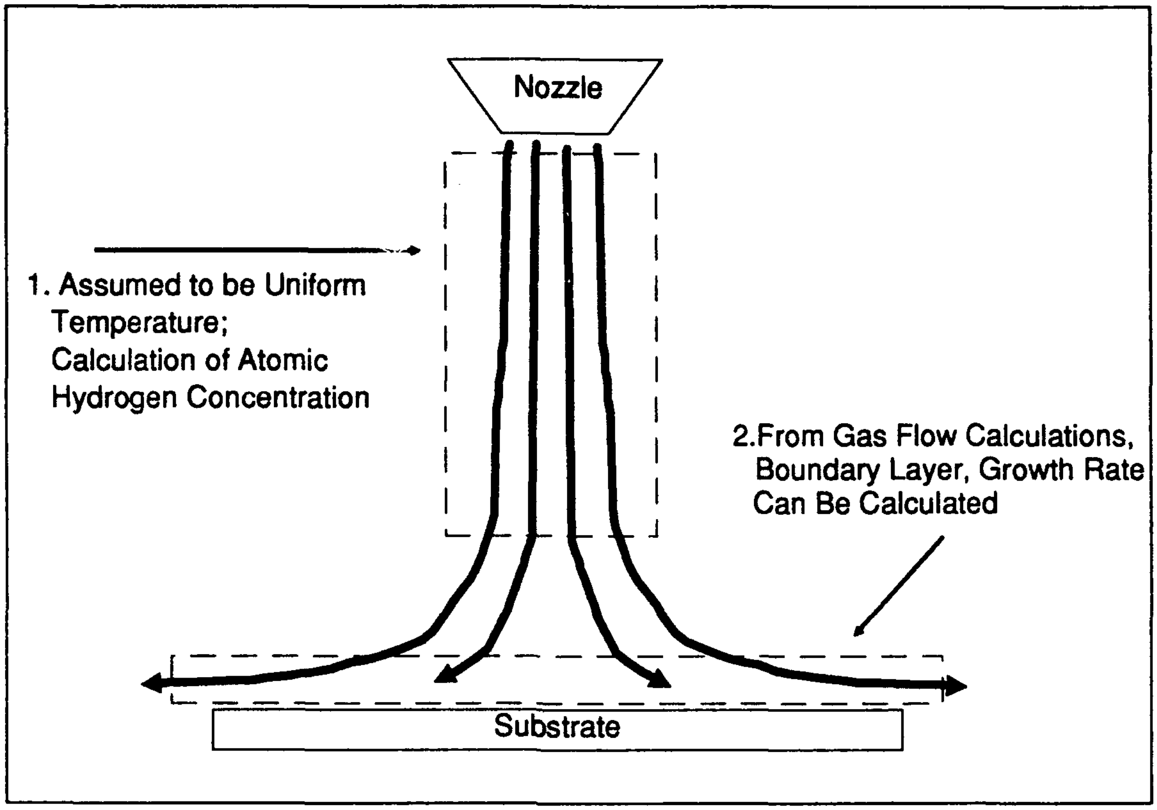


Figure 2

The gas velocity is calculated using the mass flow rate (which was calculated for the input side of the energy balance equation), the area of the gas duct (an input), the ideal gas constant, the temperature of the gas mix (an input), the pressure inside the reactor (an input) and the mean molecular weight.

Given the mole fraction of atomic hydrogen and the gas velocity, boundary layer transport theories are employed to determine the flux of hydrogen to the surface. Diamond deposition theory indicates that the linear growth rate is proportional to the concentration of atomic hydrogen at the substrate raised to some power between one and two. Using assumed values for growth rate, power and gas flow, a proportionality constant was found for the atomic hydrogen concentration exponent of two.

Linear growth rate is converted to a mass growth rate by assuming uniform growth across the surface. Mass growth rate is critical to the DC Arcjet Model because it has great impact on the costs for the deposition operation.

Sensitivity Analysis

One of the advantages of a Technical Cost Model is that it permits the flexibility of performing sensitivity analyses. Using sensitivity analyses, it is possible to explore the cost implications of changing key input variables such as production volume, material prices, product dimensions, etc. As an R&D management tool, these analyses help set development goals for cost effective manufacturing. Further, they help in long term planning, by indicating the cost savings that may be realized through scale-up. Presented in the following sections are the following analyses:

- Cost vs Gas Temperature and Substrate Area
- Cost vs Reactor Power and Substrate Area
- Cost vs Substrate Area (Constant Duct Area)

With the exception of the last sensitivity, the ratio of substrate to duct area is held constant. This constraint is due to the geometry of the DC arcjet methodology. The area of the gas duct is the cross-sectional area of the plasma jet before it is affected by the flow pattern around the substrate. For a DC arcjet CVD diamond plasma jet with a corresponding duct area impinging on an infinite plane, there will be a circular region of desirable diamond and a surrounding region of unacceptable diamond. Consider the similar case of a gas jet impinging on a substrate of the same area. As a substrate diameter increases while the duct diameter remains constant, there is a point at which the substrate extends into this zone of unacceptable diamond. Therefore, there is a maximum substrate:duct area ratio that should not be exceeded. Experts in DC arcjet CVD diamond suggest that this ratio is roughly 3:1. When the substrate diameter is varied in the following analyses, the duct diameter is adjusted so that the ratio of substrate to duct area is constant at three.

Wafer Cost per Square Centimeter vs Gas Temperature and Area

Figure 3 shows the cost per square centimeter as the gas temperature for the production run is varied for a range of wafer sizes, holding the substrate to duct area ratio (three) and reactor power (200 kW) constant. The graph shows that as the gas temperature increases, the cost of depositing a square centimeter of diamond decreases. The cost savings for increasing temperature are most dramatic at the lower end of the temperature range examined; a slight increase in temperature can result in a relatively large cost savings. At the high end of the temperature range there is little cost savings for slight increases in temperature. The equation shows the best fit for the area cost versus temperature and substrate area. This data regression shows that cost is inversely proportional to the temperature raised to the 5.45 power multiplied by substrate area raised to the 0.72 power. This relationship suggests that gas temperature is a variable of primary importance in the deposition process: an increase in temperature over the range in Figure 3 for the baseline diameter results in a cost reduction of 54%.

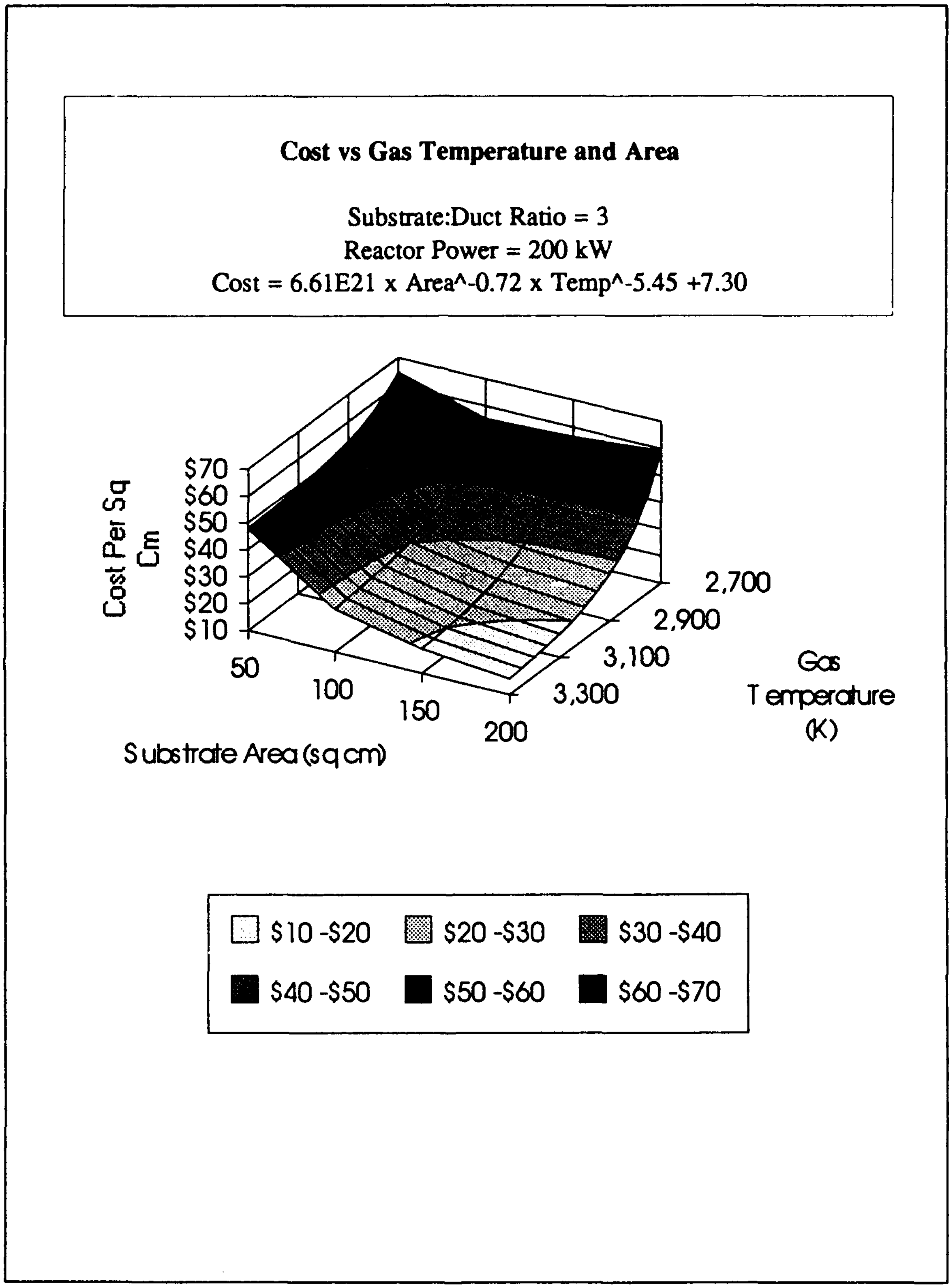

Cost vs Gas Temperature and Area
Substrate:Duct Ratio = 3
Reactor Power = 200 kW
Cost = 6.61E21 x Area^-0.72 x Temp^-5.45 +7.30
Cost Per Sq Cm
$70
$60
$50
$40
$30
$20
$10
50
100
150
200
Substrate Area (sq cm)
2,700
2,900
3,100
3,300
Gas Temperature (K)
$10 -$20
$20 -$30
$30 -$40
$40 -$50
$50 -$60
$60 -$70

Figure 3

Figure 3 also shows the relationship between cost and substrate area. Over the range of temperatures examined, the cost of depositing diamond decreases with increasing wafer sizes. The importance of increasing the substrate area is evident toward the higher temperatures, where the slope of decreasing cost is more dramatic. For the range of substrate areas and at baseline temperature, the cost is reduced by 56%. Overall, a 75% reduction in cost ($65 to $16 per square centimeter) can occur by increasing both the gas temperature from 2,700K to 3,000K and the substrate area from 50 to 200 square centimeters.

Wafer Cost per Square Centimeter vs Reactor Power and Area

Figure 4 shows the dependence of cost on reactor power and substrate area, holding the substrate to duct area ratio (three) and the gas temperature (3,000 K) constant. The cost model reports that at our baseline data set, cost per square centimeter is inversely proportional to reactor power raised to the 0.28 power. This graph suggests that cost savings due to a small increase in power are much greater in the lower end of the power range examined than in the higher end: there are diminishing returns on increasing power in the higher end of the range examined. At constant gas temperature and area, the mach number of the gas flow is nearly directly proportional to reactor power. Therefore, this graph could also represent the behavior of cost as the mach number is increased while keeping the temperature constant. A closer look at the model reveals that at constant temperature, an increase in reactor power will further heat the gas mix. To sustain a constant gas temperature, the gas flow rate (mach number) must also increase to allow more gas to pass through the system to absorb the power increase. The lower cost per square centimeter and higher deposition rates of higher power reactors, at constant temperature, can be attributed directly to higher mach numbers.

Deposition Cost per Square Centimeter vs Substrate Area (Constant Duct Area)

Figure 5 recasts the data from Figure 3 at 200 kW showing the relationship between substrate area and cost for two cases: with duct area held constant at 58 square centimeters, and with the substrate to duct area ratio maintained at three. This graph suggests that great cost reductions may be accomplished by increasing the substrate area, especially at the low end of the area range examined.

For the curve with constant duct area in Figure 5, the largest valid substrate area is roughly 180 sq cm. This upper limit is determined from the assumption that the substrate:duct area ratio should not be greater than three, and the assumption of 58 square centimeters as the baseline duct area. At the baseline gas temperature of 3,000K

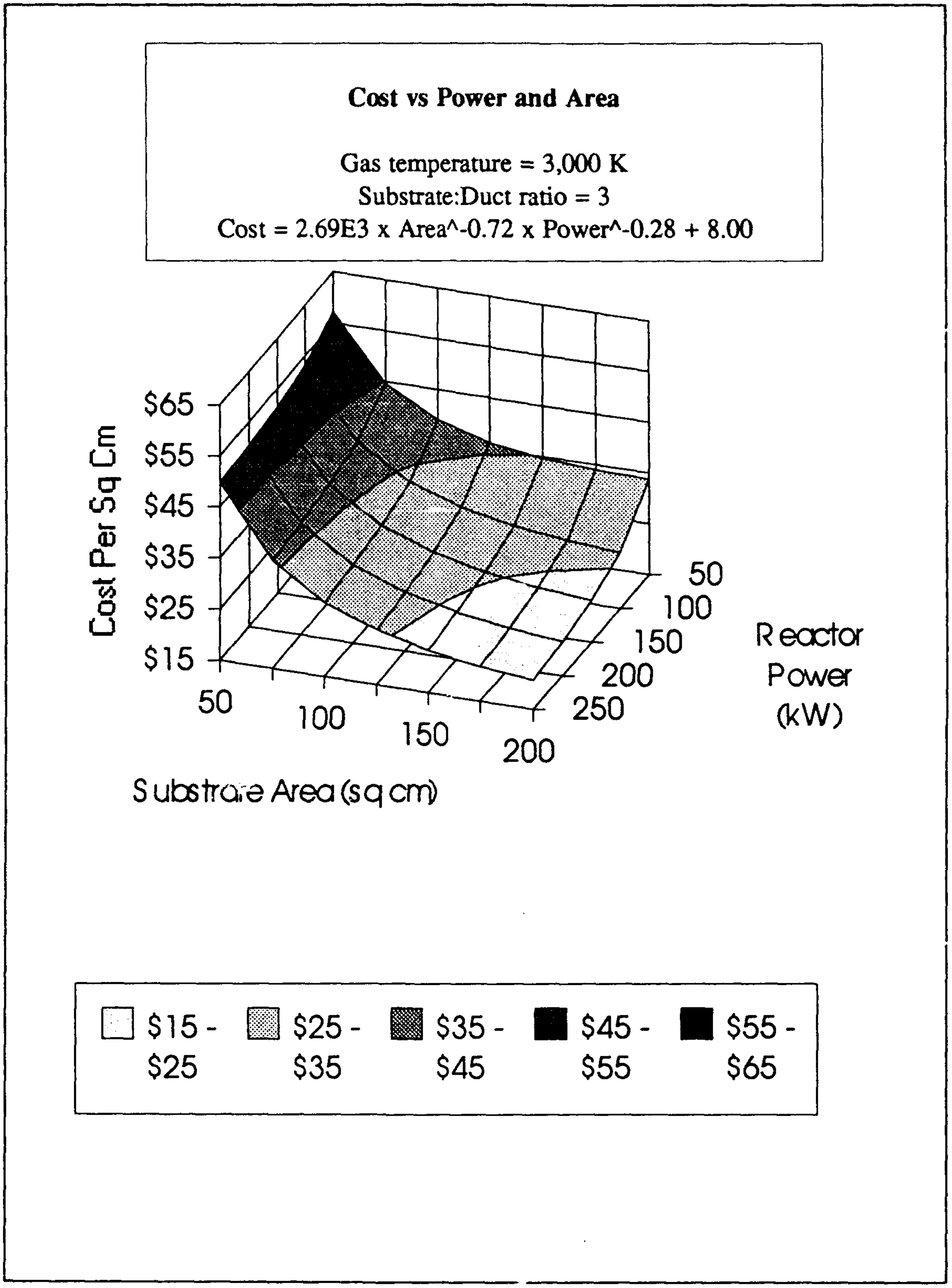

Cost vs Power and Area
Gas temperature = 3,000 K
Substrate:Duct ratio = 3
Cost = 2.69E3 x Area^-0.72 x Power^-0.28 + 8.00
Cost Per Sq Cm
$65
$55
$45
$35
$25
$15
50
100
150
200
Substrate Area (sq cm)
50
100
150
200
250
Reactor Power (kW)
$15 - $25
$25 - $35
$35 - $45
$45 - $55
$55 - $65

Figure 4

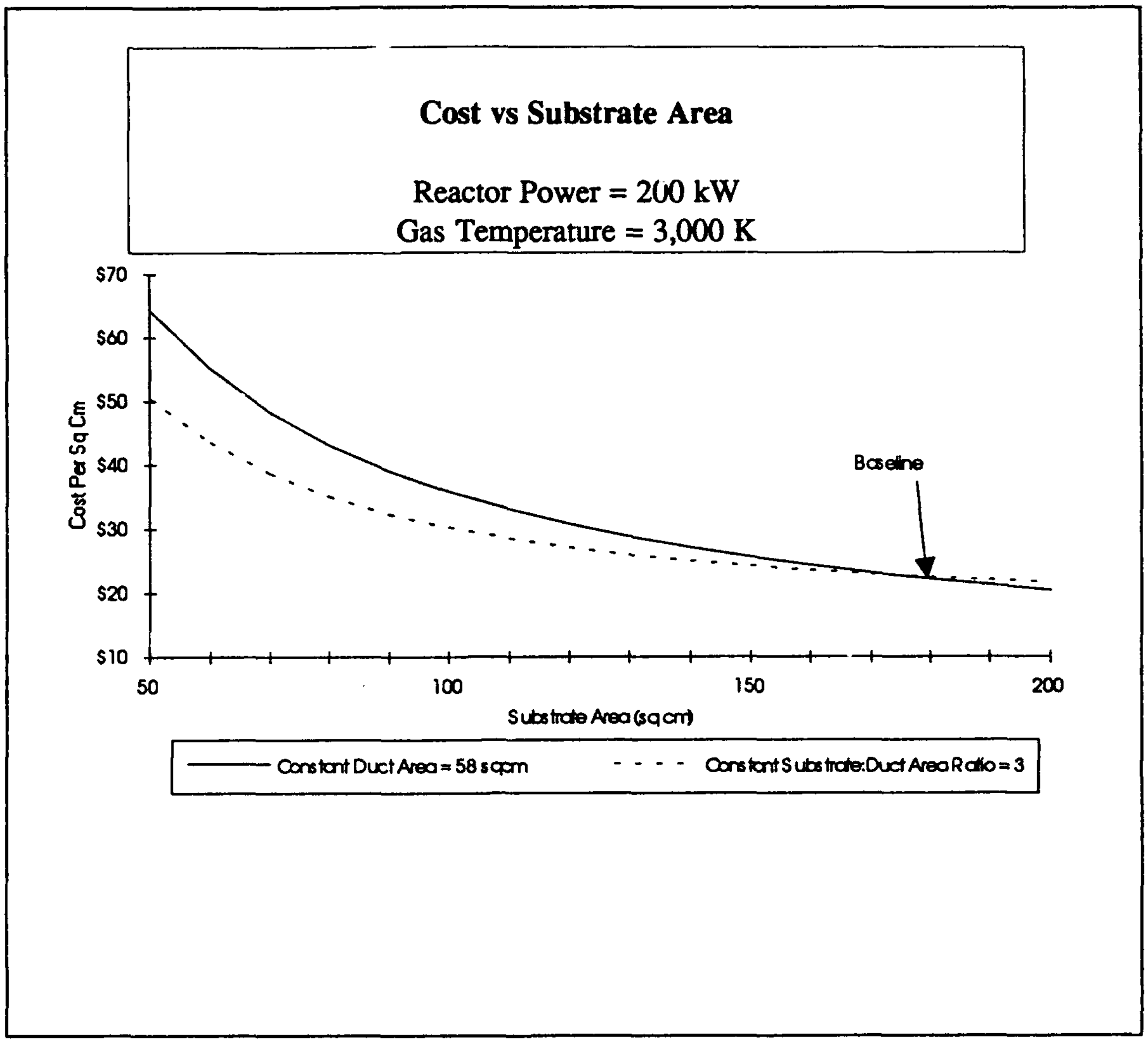


Figure 5

and reactor power of 200kW, the majority of cost reduction occurs while the substrate area is varying below this theoretical limit. The equation for this curve reveals that the cost varies inversely with the area raised to the 0.83 power, and that the cost approaches zero as the diameter nears a kilometer. Obviously, this diameter is infeasible, especially for such a duct area. The economics of substrate scale-up can be better examined by increasing the duct area with the substrate area to maintain a constant ratio.

Figure 5 also shows the result of this investigation by varying the substrate diameter while holding the substrate:duct ratio and gas temperature constant. From this graph, it is apparent that increasing the substrate area reduces cost significantly, even with the substrate:duct area ratio maintained at three. At the 200 kW baseline power, the cost per square centimeter varies inversely with the substrate area raised to the 2.01 power. For this graph, the cost reduces by 75% over the range of areas examined.

Future Work

Working towards a more powerful version of the DC Arcjet Model, a few goals remain. First, expert review is in progress and will continue for the duration of the project. Second, as mentioned in the Executive Summary, work remains in establishing correlations between growth rate and yield, and substrate diameter and yield. Lastly, investigations into alternative finishing technologies continue, with the goal of identifying preferable techniques.

Microwave Model

The progress of the Microwave Model has involved the incorporation of deposition theory into the cost model. This has been accomplished with the help of Professor David Goodwin of Caltech. Based on expert review of the microwave deposition theory, however, two versions of the IBIS Microwave CVD Diamond Technical Cost Model were developed: one model which uses the empirical relationship between growth rate and input microwave power only (printout in Appendix B), and one model which uses the hydrogen diffusion theory to determine growth rate (printout in Appendix C). IBIS has been conducting analyses with both models and soliciting expert review for their approval. The descriptions of microwave deposition and the diffusion theory are in the following sections.

Microwave Deposition

The microwave deposition operation involves the formation of the diamond film. The diamond growing substrate is mounted on a heated fixture perpendicular to the direction of flow in a gas flow tube (usually quartz), which is at a controlled pressure. The microwave generator is affixed outside of the sealed gas flow tube such that the tube's cross-sectional volume of energized gas is close to the substrate. The generator itself is contained in a radiation-proof jacket for safety considerations. A controlled mix of gases passes through the reaction chamber, and the frequency (usually about 2.45 GHz) is set so as to excite the gas into a plasma. The diamond then grows on the substrate, which is positioned on the periphery of the plasma ball. The relationship between this diamond growth rate and the deposition parameters is described in the next section.

Application of Zero-Order Hydrogen Plasma Diffusion Theory to the Model

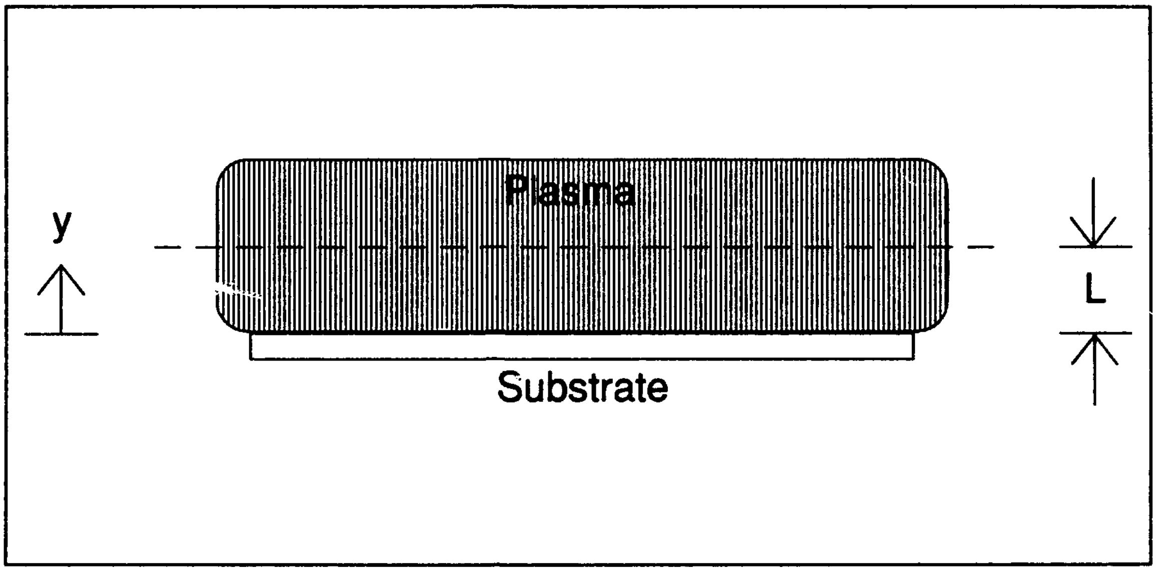
This section outlines a reduced mechanism for diamond growth which leads to a closed-form expression for the growth rate in terms of the local chemical environment at the substrate. The issue of atomic hydrogen transport to the substrate is considered in depth and relations are presented to allow the rapid estimation of the H concentration at the substrate for specified process parameters in diffusion-dominated flows.

This model assumes:

- *One dimensional diffusion*
- *No convective transport ($Pe<<1$)*
- *Neglect temperative gradients*
- *Constant atomic hydrogen volumetric production rate in the plasma*
- *Fraction of absorbed power used to dissociate H_2*

— *Negligible homogeneous recombination of H to H_2*

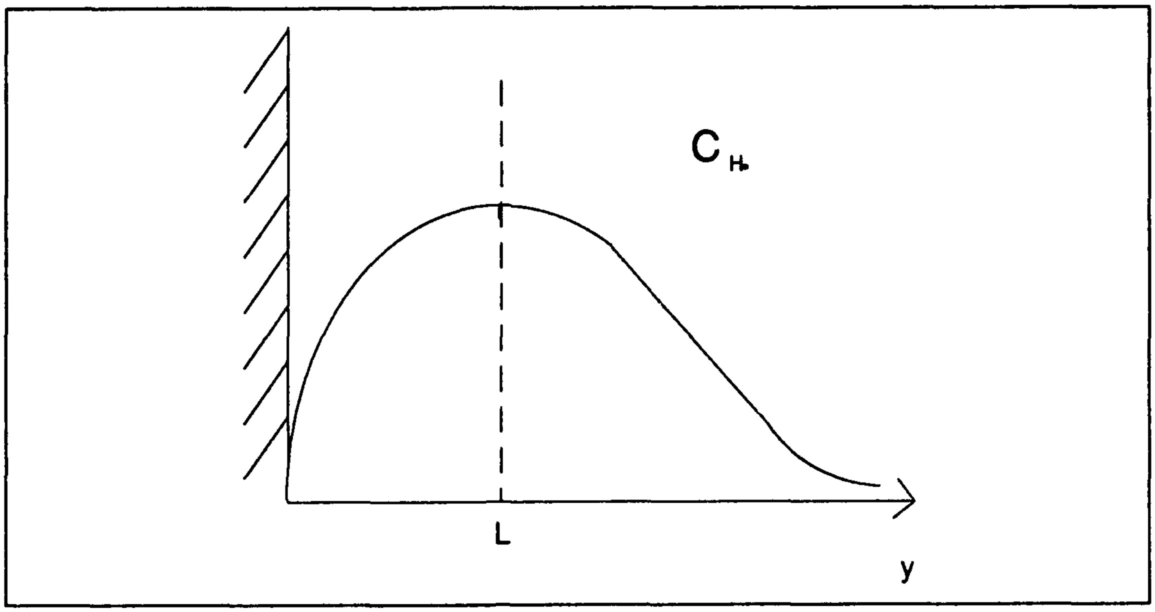
Consider the following geometry:



where L is the distance from the substrate to the "center" of the plasma and $C_{H\cdot}$ is the atomic hydrogen concentration. The "center" of the plasma is defined such that:

$$\left.\frac{d\,C_{H\cdot}}{d\,y}\right|_{y=L} = 0$$

And the H concentration can be described by



Let C_H = H concentration (moles/cm3), then the 1-D diffusion equation is

$$D \frac{d^2 C_{H\cdot}}{d y^2} = - \dot{P}_{H\cdot}$$

Where D is the diffusion coefficient (m^2/s) and P_H is the H volumetric production rate.

Boundary Conditions

Substrate:

Due to the conservation of mass, the flux of H to surface is equal to the recombination rate. At the substrate, the conservation of mass can be described by

$$C_{H\cdot}(0) - \frac{\lambda_{H\cdot}}{\gamma} \left(\frac{d C_{H\cdot}}{d y} \right)_{y=0} = 0$$

where $\lambda_{H\cdot}$ is defined as defined as 4D / $\overline{V_{H\cdot}}$ ($\overline{V_{H\cdot}}$ is the mean thermal speed) and γ is the recombination coefficient.

Center:

From our definition of L, the change of H concentration at the center of the plasma ball is

$$\left(\frac{d\,C_{H\cdot}}{d\,y}\right)_{y=L} = 0$$

Solution of the 1-D Diffusion Equation

The solution to the 1-D diffusion subject to the boundary conditions is

$$C_{H\cdot}(y) = \frac{\dot{P}_{H\cdot}}{D}\left[L\,y - \frac{y^2}{2} + \frac{\lambda_{H\cdot}}{\gamma}L\right]$$

And at y=0

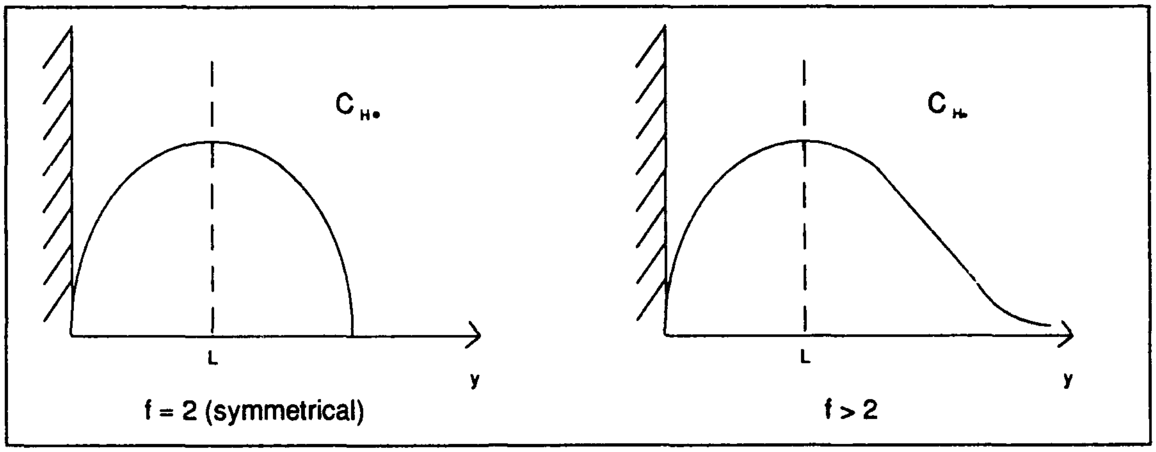
$$C_{H\cdot}(0) = \frac{4\,\dot{P}_{H\cdot}\,L}{\overline{V}_{H\cdot}\,\gamma}$$

Now the H volumetric production rate is

$$\dot{P}_{H\cdot} = \varepsilon\frac{W}{V\,\Delta H}$$

where W is the power coupled to the plasma, V is the plasma volume, ΔH is the enthalpy of reaction for $H_2 >$ H and ε is the efficiency factor to account for power lost to line radiation or other losses.

Assume that V = f A L where A is the plasma ball footprint or deposition area, which is a function of power at a given pressure, L is the height of the center of the plasma ball and f is a geometrical factor that defines the relationship between the physical center of the plasma and the center as determined by the zero $C_{H\cdot}$ gradient:



Substituting the H volumetric production rate into the 1-D diffusion equation results in

$$C_{H\cdot}(0) = \frac{4\,\varepsilon\,W}{\overline{V_{H\cdot}}\,\gamma\,f\,A\,\Delta H}$$

A comparison between an estimate of H concentration and a data point provided by Hsu[1] results in a value of 0.2 for the efficiency factor ε.

Once the atomic hydrogen concentration at the substrate has been calculated then the linear growth rate can be estimated by

$$\text{Linear Growth Rate} = z\,[\,C_{H\cdot}(0)\,]^{n}$$

Where z is a calibration factor and n is between 1 and 2.

1 Hsu, J. Appl. Phys. 72, 3102-3109, (1992)

Future Work

Working towards a more powerful version of the Microwave Model, a few goals remain. First, expert review is in progress and will continue for the duration of the project. Second, as mentioned in the Executive Summary, work remains in establishing correlations between growth rate and yield, and substrate diameter and yield. Third, an investigation into the cost of new microwave tube prices and issues of tube reusability is currently being conducted. Lastly, investigations into alternative finishing technologies continue, with the goal of identifying preferable techniques.

Sensitivity Analysis

For the diffusion version of the model, two sensitivity analyses are presented below to indicate the sensitivity of cost to two inputs that cannot be easily characterized at this time.

The sensitivity analyses presented are

- Cost Per Sq Cm vs Reactor Power and Surface Recombination Coefficient
- Cost Per Sq Cm vs Reactor Power and Plasma Ball Skew Factor (f)

One assumption which extends through each of the analyses is that the deposition area is assumed to be a function of the reactor power. As the power of the reactor increases, the deposition area also increases.

Wafer Cost Per Square Centimeter vs Reactor Power and Surface Recombination Coefficient

Figure 6 shows the cost per square centimeter as a function of the coefficient describing the atomic hydrogen recombination at the substrate surface at various reactor powers. The graph shows that the cost is very strongly dependent on the surface recombination factor, especially at the low end of the reactor power scale. Even though the cost difference is most dramatic at the low end of the reactor power scale it should be noted that the difference in cost resulting from a surface recombination coefficient change from 0.2 to 0.05 results in an order of magnitude drop in cost all along the reactor power scale. The 50 kW reactors, which represent the low end of the reactor power scale, are among the state-of-the-art near term reactors. As stated earlier in this report, the surface recombination factor has not been studied to the extent that it can be easily characterized or predicted. Further research in this area will permit more accurate estimation of microwave CVD costs.

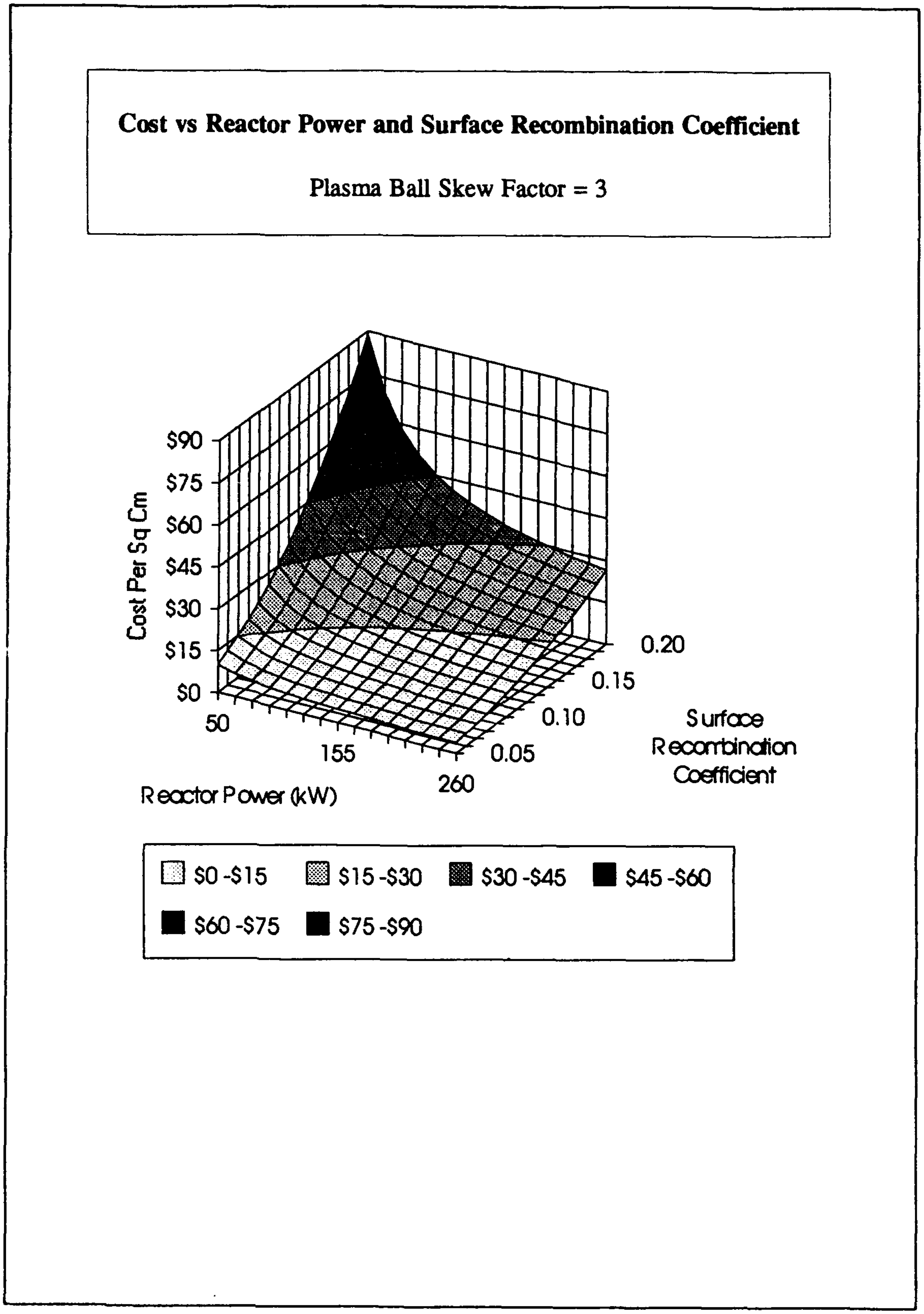
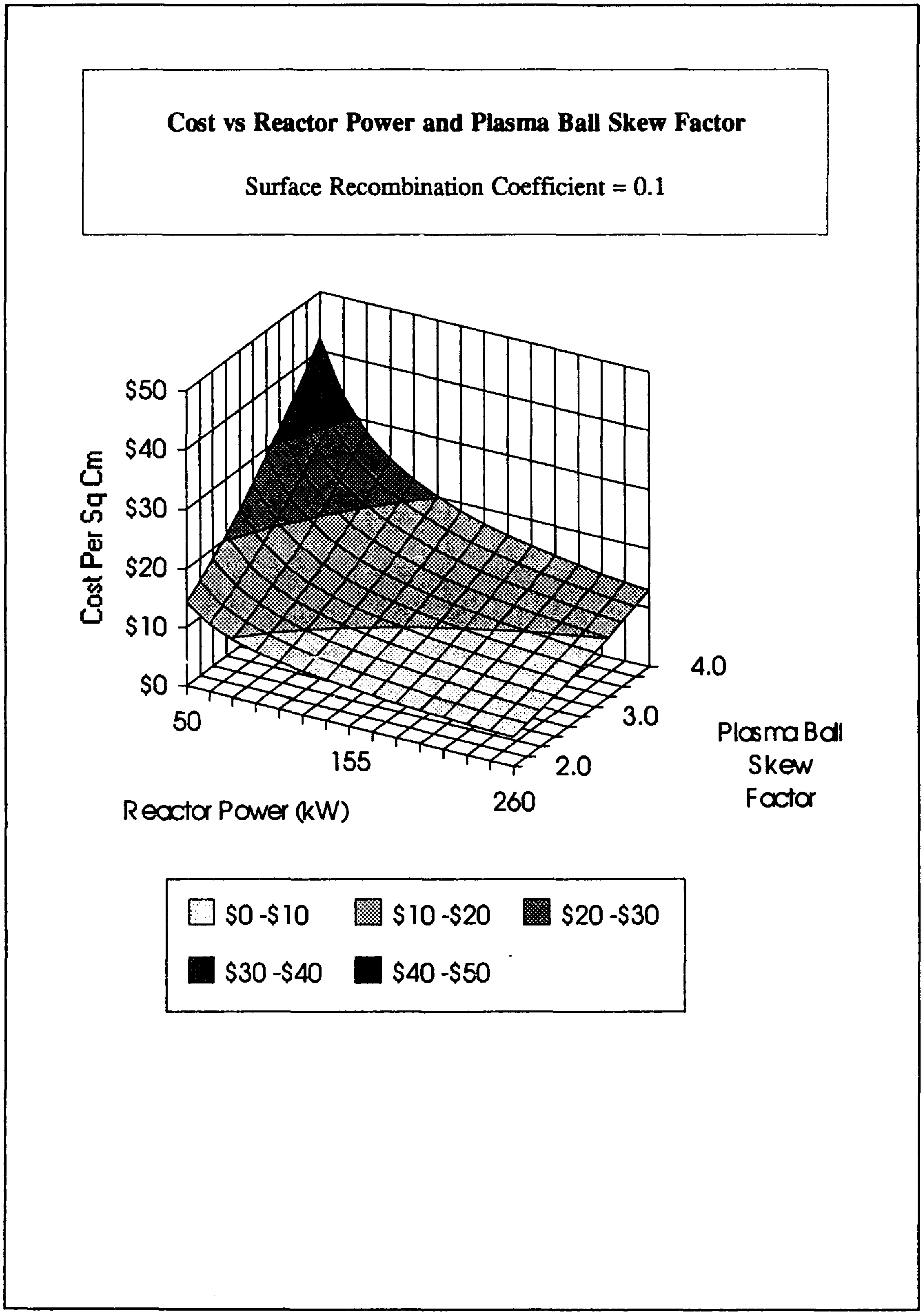

Cost vs Reactor Power and Surface Recombination Coefficient
Plasma Ball Skew Factor = 3
Cost Per Sq Cm
$90
$75
$60
$45
$30
$15
$0
50
155
260
Reactor Power (kW)
0.05
0.10
0.15
0.20
Surface Recombination Coefficient
$0-$15
$15-$30
$30-$45
$45-$60
$60-$75
$75-$90

Figure 6

Wafer Cost Per Square Centimeter vs Reactor Power and Plasma Ball Skew Factor

Figure 7 shows the cost per square centimeter as a function of the plasma ball skew factor at various reactor powers. The graph shows that cost is strongly dependent on the plasma ball skew factor. As the plasma ball skew factor decreases from a value of 4 to 2 the cost per square centimeter drops by a factor of 3. Again, the low end of the scale on this graph represents the state-of-the-art near term reactor. Like the surface recombination coefficient, the plasma ball skew factor has not been studied to the extent that it can be easily characterized or predicted. The plasma ball skew factor is most likely strongly dependent on reactor geometry, so even if there was existing research in this area it may be difficult to apply that research to a generic microwave model. However, further research in this area will permit more accurate estimation of microwave CVD costs.



Cost vs Reactor Power and Plasma Ball Skew Factor
Surface Recombination Coefficient = 0.1
Cost Per Sq Cm
$50
$40
$30
$20
$10
$0
50
155
260
Reactor Power (kW)
4.0
3.0
2.0
Plasma Ball Skew Factor
$0 -$10
$10 -$20
$20 -$30
$30 -$40
$40 -$50

Figure 7

Summary & Conclusions

IBIS Associates, through Technical Cost Modeling (TCM), has updated its predictive spreadsheet models of the DC arcjet and microwave diamond deposition technologies. This report presents the results obtained with the new models and a revised set of baseline inputs for diamond heat sink manufacture.

The cost of producing 1,000 polished diamond wafers, 1 mm thick, is estimated in the long run to be $23.70 per square centimeter by the DC arcjet deposition technology (six inch diameter), and $8.49 per square centimeter by the microwave deposition technology (sixteen inch diameter). However, each of these estimates embodies many uncertain assumptions, and these estimates will be refined as work continues.

The major revision of the DC Arcjet Model is the inclusion of the kinetic theory of DC arcjet deposition into the model. According to this theory, the key factors driving the cost of thermal management diamond produced by the DC arcjet technology are the gas temperature, the power of the reactor, and the substrate diameter. It was shown that maximizing the gas temperature is critical to reducing the cost of the diamond wafer due to its dramatic effect on growth rate.

The major revision of the Microwave Model is the incorporation of similar theory of deposition kinetics, adapted to the typical conditions of microwave deposition. According to the model, the key factor driving the cost of thermal management diamond produced by the microwave technology is the reactor power. It is determined that research into atomic hydrogen surface recombination and plasma ball shaping factors would increase the accuracy of cost predictions.

To be investigated further are the relationships between diamond growth rate and process yield for both the DC arcjet and microwave technologies. It is expected that as the growth rate increases, the yield decreases; yet a specific relation between these factors is unknown. Similarly, the relationship between substrate diameter and yield requires further investigation, due to the known complications with the increase of this parameter. Lastly, expert approval of the models is continually in progress.

Appendix A

DC ARC-JET CVD DIAMOND TECHNICAL COST MODEL - LONG TERM
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Revision Date: 9/93

PRODUCT SPECIFICATIONS

Part Name	6 in. substrate		NAME
Wafer Diameter	15.24	cm	WAFER
Finished Wafer Thickness	1,000	um	THIK
Annual Production Volume	1.0	(000/yr)	NUM
Length of Production Run	5.00	yrs	PLIFE

PROCESS RELATED FACTORS - SURFACE PREPARATION

Process In Use?	1.00	[1=Y 0=N]	USE1
Dedicated Investment	1.00	[1=Y 0=N]	DED1
Process Yield	95.0%		YLD1
Average Equipment Downtime	20.0%		DOWN1
Direct Laborers Per Station	0.50		NLAB1
Substrate Material	11.00	[menu #]	MATL1
Pieces Per Batch	20.00	pcs/batch	PCS1
Process Time	60.00	min/batch	PTIME1
Building Space Requirement	250	sqft/sta	FLR1

PROCESS RELATED FACTORS - DEPOSITION

Process In Use?	1.00	[1=Y 0=N]	USE2
Dedicated Investment	1.00	[1=Y 0=N]	DED2
Process Yield	87.5%		YLD2
Average Equipment Downtime	15.0%		DOWN2
Direct Laborers	0.40	/sta	NLAB2
Machine Power	200	kW	POW2
Power to Gas Efficiency	0.40		P2GEFF
Machine Load/Unload Time	120.00	min/batch	PTIME2
Available Deposition Time	8,640	hrs/yr	DAYHR2
Coolant Temp. Rise	50.00	C	TEMP2
Heat Capacity of Coolant	1.0	cal/g/C	CP2
Building Space Requirement	1,500	sqft/sta	FLR2
Reactor Pressure	50.0	torr	RPRESS
Substrate Temperature	1,173	K	STEMP
Gas Temperature (>1000K)	3,000	K	GTEMP
Hydrogen Gas Flow Rate	393.6	slm	HFLOW
Carbon Fas Flow Rate	0.4	slm	CFLOW
Argon Gas Flow Rate	196.8	slm	ARFLOW
Other Gas Flow Rate	0.0	slm	OGFLOW
Total Gas Flow Rate	590.76	slm	

	Menu #	vol%	
Hydrogen	1	66.6%	GASA VOLA

DC ARC-JET CVD DIAMOND TECHNICAL COST MODEL - LONG TERM
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GAS DATABASE

#	Gas	Source	Purity	Price $/SCM	No. of Carbons	Liq Gas	Tank gal	Price Update
0	None			$0.00	0.00	0.00		
1	Liq Hydrogen	Airco	99.998%	$0.34	0.00	1.00	6000	1/93
2	Liq Hydrogen	Airco	99.998%	$0.32	0.00	1.00	11000	1/93
3	Liq Hydrogen	Airco	99.998%	$0.30	0.00	1.00	20000	1/93
4	Liq Argon	Airco	99.998%	$1.41	0.00	1.00	3000	1/93
5	Liq Argon	Airco	99.998%	$1.32	0.00	1.00	6000	1/93
6	Liq Argon	Airco	99.998%	$1.29	0.00	1.00	11000	1/93
7	Hydrogen	MG Ind.	99.9999%	$29.86	0.00	0.00		1/93
8	Hydrogen	MG Ind.	99.9996%	$40.61	0.00	0.00		1/93
9	Hydrogen	MG Ind.	99.999%	$10.28	0.00	0.00		1/93
10	Hydrogen	Air Prod.	99.95%	$1.59	0.00	0.00		1/93
11	Argon	MG Ind.	99.9999%	$33.09	0.00	0.00		1/93
12	Argon	Air Prod.	99.9997%	$37.33	0.00	0.00		1/93
13	Argon	Air Prod.	99.999%	$11.74	0.00	0.00		1/93
14	Argon	Air Prod.	99.997%	$2.03	0.00	0.00		1/93
15	Methane	Air Prod.	99.99%	$21.99	1.00	0.00		1/93
16	Methane	Air Prod.	99%	$13.76	1.00	0.00		1/93
17	Methane	Air Prod.	93%	$4.93	1.00	0.00		1/93
18	Acetylene	Air Prod.	99.6%	$6.80	2.00	0.00		1/93
19	Acetylene	Air Prod.	98%	$5.85	2.00	0.00		1/93
20	Helium	Air Prod.	99.9995%	$15.90	0.00	0.00		1/93
21	Helium	Air Prod.	99.995%	$4.77	0.00	0.00		1/93
22	Nitrogen	Air Prod.	99.9996%	$45.50	0.00	0.00		1/93
23	Nitrogen	MG Ind.	99.999%	$9.23	0.00	0.00		1/93
24	Nitrogen	Air Prod.	99.998%	$1.24	0.00	0.00		1/93
25	Oxygen	Air Prod.	99.998%	$2.00	0.00	0.00		1/93
26								

SUBSTRATE DATABASE

#	Substrate	Source	Price $/ea	Thick um	Diam cm	Etch um/min	Life use#	Price Update
0	None		$0.00	1	1.00	1.00	1.00	
1	Silicon	Si-Tech	$2.65	1270.00	5.08	20.00	1	1/93
2	Silicon	Si-Tech	$3.50	1270.00	7.62	20.00	1	1/93
3	Silicon	Si-Tech	$6.25	1270.00	10.16	20.00	1	1/93
4	Silicon	Si-Tech	$9.70	1270.00	12.70	20.00	1	1/93
5	Silicon	Si-Tech	$18.60	1270.00	15.24	20.00	1	1/93
6	Silicon	Si-Tech	$57.95	1270.00	20.32	20.00	1	1/93
7	Silicon	Si-Tech	$4.35	3810.00	5.08	20.00	1	1/93
8	Silicon	Si-Tech	$8.15	3810.00	7.62	20.00	1	1/93
9	Silicon	Si-Tech	$14.50	3810.00	10.16	20.00	1	1/93
10	Silicon	Si-Tech	$22.65	3810.00	12.70	20.00	1	1/93

Carbon Containing Gas	15	0.1%	GASB VOLB
Carrier Gas	4	33.3%	GASC VOLC
Other Gas	0	0.0%	GASD VOLD
		100.0%	

Hydrogen Recycle Rate	0.0%		RECYC
Carrier Gas Recycle Rate	0.0%		RECYC2
Gas Recycle Equipment Cost	$250,000	total	MCH2A
Recombine Coef. (gammaH)	0.10		RECOMBX
Substrate:Duct Area Ratio	3.00		SUBDUCT
Substrate Shape Factor (c)	1.00		SHAPFAC
Hydrogen Concentration Exp	2.00		HEXP
Diamond Quality Factor (Z)	2.50E-18	??????!	ZFAC
Diamond Density	3.52	g/cc	DENS
Ideal Gas Constant (R)	62,358	c torr/K mol	IDEALG1
Ideal Gas Constant 2 (R)	8.31	J / mol K	IDEALG2

NASA Enthalpy Constants	H2	H	Ar
a1	2.99E+00	2.50E+00	2.50E+00
a2	7.00E-04	0.00E+00	0.00E+00
a3	-5.63E-08	0.00E+00	0.00E+00
a4	-9.23E-12	0.00E+00	0.00E+00
a5	1.58E-15	0.00E+00	0.00E+00
a6	-8.35E+02	2.55E+04	-7.45E+02
a7	-1.36	-0.46	4.37
MW	2.02	1.01	39.95

PROCESS RELATED FACTORS - ETCHING

Process In Use?	1.00	[1=Y 0=N]	USE3
Dedicated Investment	1.00	[1=Y 0=N]	DED3
Process Yield	99.0%		YLD3
Average Equipment Downtime	10.0%		DOWN3
Direct Laborers Per Station	1.00		NLAB3
Load/Unload and Rinse Time	30.00	min/batch	PTIME3
Pieces Per Batch	20.00		PCS3
Machine Cost	$6,000	/sta	MCH3
Etchant Cost	$70	/liter	ETCH3A
Etchant Disposal Cost	$30	/liter	ETCH3B
Machine Etchant Capacity	1.00	l/batch	CAP3
Machine Power	0.00	kW	POW3
Building Space Requirement	100	sqft/sta	FLR3

PROCESS RELATED FACTORS - LASER TRIMMING

Process In Use?	1.00	[1=Y 0=N]	USE4
Dedicated Investment	1.00	[1=Y 0=N]	DED4
Process Yield	99.0%		YLD4
Average Equipment Downtime	10.0%		DOWN4
Direct Laborers Per Station	1.00		NLAB4
Machine Cost	$6,000	/sta	MCH4

11	Silicon	Si-Tech	$43.45	3810.00	15.24	20.00	1	1/93
12	Silicon	Si-Tech	$135.20	3810.00	20.32	20.00	1	1/93
13	Silicon	Si-Tech	$6.85	6350.00	5.08	20.00	1	1/93
14	Silicon	Si-Tech	$12.80	6350.00	7.62	20.00	1	1/93
15	Silicon	Si-Tech	$22.75	6350.00	10.16	20.00	1	1/93
16	Silicon	Si-Tech	$35.55	6350.00	12.70	20.00	1	1/93
17	Silicon	Si-Tech	$68.30	6350.00	15.24	20.00	1	1/93
18	Silicon	Si-Tech	$212.45	6350.00	20.32	20.00	1	1/93
19	Molybdenum	Phil. Elmet	$3.90	254	5.08	10.00	1	1/93
20	Molybdenum	Phil. Elmet	$8.20	254	10.16	10.00	1.00	1/93
21	Molybdenum	Phil. Elmet	$14.50	254	15.24	10.00	1.00	1/93
22	Molybdenum	logies Corp	$25.35	254	20.32	10.00	1.00	1/93
23	Molybdenum	logies Corp	$4.80	508.00	5.08	10.00	4	1/93
24	Molybdenum	logies Corp	$14.75	508.00	10.16	10.00	4	1/93
25	Molybdenum	logies Corp	$24.30	508.00	15.24	10.00	4	1/93
26	Molybdenum	logies Corp	$37.10	508.00	20.32	10.00	4	1/93
27	Molybdenum	Phil. Elmet	$9.15	1524.00	5.08	10.00	20	1/93
28	Molybdenum	logies Corp	$27.60	1524.00	10.16	10.00	20	1/93
29	Molybdenum	logies Corp	$52.25	1524.00	15.24	10.00	20	1/93
30	Molybdenum	logies Corp	$85.25	1524.00	20.32	10.00	20	1/93
31	Molybdenum	logies Corp	$14.75	2286.00	5.08	10.00	32.00	1/93
32	Molybdenum	logies Corp	$36.00	2286.00	10.16	10.00	32.00	1/93
33	Molybdenum	logies Corp	$69.00	2286.00	15.24	10.00	32.00	1/93
34	Molybdenum	logies Corp	$113.50	2286.00	20.32	10.00	32.00	1/93
35	Molybdenum	logies Corp	$18.50	3175.00	5.08	10.00	46.00	1/93
36	Molybdenum	logies Corp	$46.75	3175.00	10.16	10.00	46.00	1/93
37	Molybdenum	logies Corp	$90.50	3175.00	15.24	10.00	46.00	1/93
38	Molybdenum	logies Corp	$149.00	3175.00	20.32	10.00	46.00	1/93
39	Tungsten	logies Corp	$7.75	254	5.08	10.00	1	1/93
40	Tungsten	logies Corp	$24.50	254	10.16	10.00	1.00	1/93
41	Tungsten	logies Corp	$50.00	254	15.24	10.00	1.00	1/93
42	Tungsten	logies Corp	$79.25	254	20.32	10.00	1.00	1/93
43	Tungsten	logies Corp	$10.00	508.00	5.08	10.00	4.00	1/93
44	Tungsten	logies Corp	$35.10	508.00	10.16	10.00	4.00	1/93
45	Tungsten	logies Corp	$67.00	508.00	15.24	10.00	4.00	1/93
46	Tungsten	logies Corp	$109.20	508.00	20.32	10.00	4.00	1/93
47	Tungsten	logies Corp	$50.00	1524.00	5.08	10.00	20.00	1/93
48	Tungsten	logies Corp	$112.00	1524.00	10.16	10.00	20.00	1/93
49	Tungsten	logies Corp	$317.00	1524.00	15.24	10.00	20.00	1/93
50	Tungsten	logies Corp	$422.00	1524.00	20.32	10.00	20.00	1/93
51	Tungsten	logies Corp	$60.00	3175.00	5.08	10.00	46.00	1/93
52	Tungsten	logies Corp	$161.25	3175.00	10.16	10.00	46.00	1/93
53	Tungsten	logies Corp	$521.30	3175.00	15.24	10.00	46.00	1/93
54	Tungsten	logies Corp	$687.00	3175.00	20.32	10.00	46.00	1/93
55								
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Trimming Rate	1.00	cm/s	RATE4
Machine Power	0.00	kW	POW4
Building Space Requirement	100	sqft/sta	FLR4
PROCESS RELATED FACTORS - LAPPING			
Process In Use?	1.00	[1=Y 0=N]	USE5
Dedicated Investment	1.00	[1=Y 0=N]	DED5
Process Yield	90.0%		YLD5
Average Equipment Downtime	15.0%		DOWN5
Direct Laborers Per Station	1.00		NLAB5
Lapped Material Removal	10.0%	by wgt	TLAP5
No of Lapping Steps	2.00		LAPS5
Pieces Per Batch	5.00		PCS5
Load/Unload and Clean Wafers	40.00	min/batch	PTIME5
Average Lapping Rate	1.0	um/hr	RATE5
Lapping Slurry Cost	$53	/liter	LAPSL5
Lapping Slurry Usage Rate	0.50	liter/hr	LAPR5
Lapping Plate Life	320.00	hrs	PLAL5
Available Lapping Time	8,640	hrs/yr	DAYHR5
Building Space Requirement	400	sqft/sta	FLR5
			/rnd
PROCESS RELATED FACTORS - INSPECTION - MICROSCOPY			
Process In Use?	1.00	[1=Y 0=N]	USE6
Dedicated Investment	1.00	[1=Y 0=N]	DED6
Process Yield	95.0%		YLD6
Average Equipment Downtime	5.0%		DOWN6
Direct Laborers Per Station	1.00		NLAB6
Average Inspection Time	15.00	min/batch	PTIME6
Percent Inspection	100%		INSP6
Machine Cost	$50,000	/sta	MCH6
Machine Power	0.10	kW	POW6
Building Space Requirement	50	sqft/sta	FLR6
PROCESS RELATED FACTORS - INSPECTION - THERMAL CONDUCTIVITY			
Process In Use?	1.00	[1=Y 0=N]	USE7
Dedicated Investment	1.00	[1=Y 0=N]	DED7
Process Yield	95.0%		YLD7
Average Equipment Downtime	5.0%		DOWN7
Direct Laborers Per Station	1.00		NLAB7
Average Inspection Time	15.00	min/batch	PTIME7
Percent Inspection	100%		INSP7
Machine Cost	$50,000	/sta	MCH7
Machine Power	0.10	kW	POW7
Building Space Requirement	50	sqft/sta	FLR7

OPTIONAL INPUTS

	override	estimate

Surface Preparation					
Machine Cost	$0	$65,774	/sta	OMCH1	
Machine Power	0.0	19.2	kW	OPOW1	
Deposition					
Duct Area	0.00	60.80	sqcm	ODAREA2	
Deposition Rate	0.00	4.95	g/hr	ODRATE2	
Deposition Equipment Cost	$0	$512	k$/sta	OMCH2	
Etching					
Process Cycle Time	0.00	0.18	hrs	OCTIME3	
Chemical Requirement	$0	$5.00	/pc	OCHEM3	
Laser Trimming					
Process Cycle Time	0.00	0.01	hrs	OCTIME4	
Lapping					
Lapping Time	0.00	111.11	hrs	OCTIME5	
Lapping Plate Cost	$0	$869	/ea	OWHEEL5	
Lapping Machine Cost	$0	$11,939	/sta	OMCH5	
Lapping Machine Power	0.00	4.2	kW	OPWR5	

EXOGENOUS COST FACTORS				
Direct Wages	$13.33	/hr	WAGE	
Indirect Salary	$50,000	/yr	SALARY	* exc. dep. & lap
Indirect:Direct Labor Ratio	1.00		ILAB	
Benefits on Wage and Salary	35.0%		BENI	
Working Days per Year	360.00		DAYS	
Working Hours per Day (*)	8.00	/hr	HRS	
Capital Recovery Rate	10%		CRR	
Capital Recovery Period	5.00	yrs	ELIFE	
Building Recovery Life	20.00	yrs	BLIFE	
Working Capital Period	3.00	months	WCP	
Price of Electricity	$0.050	/kWh	ELEC	
Price of Natural Gas	$6.50	/MBTU	GAS	
Price of Building Space	$100	/sqft	PBLD	
Price of Cooling Water	$0.03	/100 gal	WATER	
Auxiliary Equipment Cost	15.0%		AUX	
Equipment Installation Cost	35.0%		INST	
Maintenance Cost	8.0%		MNT	

REGRESSION CONSTANTS, COEFFICIENTS, AND EXPONENTS

-Surface Preparation-		
Machine Cost Constant	1,334	MCH1A
Machine Cost Capacity Coef	3,222	MCH1B
Machine Power Constant	-0.75	PWR1A
Machine Power Capacity Coef	1.00	PWR1B
-Deposition-		
Deposition Rate Constant	0.009	CYC2
Machine Cost Power Coef	43,500	MCH2Y
Machine Cost Power Exponent	0.40	MCH2Z
Machine Cost Power Constant	150,000	MCH2X
Tank 1 $ Capacity Constant	1,175	TANK2A
Tank 1 $ Capacity Coef	0.165	TANK2B

Tank 2 $ Capacity Constant	370.00	TANK2X
Tank 2 $ Capacity Coef	0.03	TANK2Y
-Etching-		
-Lapping-		
Machine Cost Constant	2,719	MCH5A
Machine Cost Capacity Coef	1,844	MCH5B
Machine Power Constant	-0.75	PWR5A
Machine Power Capacity Coef	1.00	PWR5B
Tool Cost Constant	771.00	TOOL5A
Tool Cost Capacity Coef	0.92	TOOL5B
Tool Cost Capacity Exponent	2.90	TOOL5C

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DC ARC CVD TCM: SURFACE PREPARATION
IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$65.66	$65,660	50.0%	
Direct Labor Cost	$0.85	$850	0.6%	
Utility Cost	$0.07	$72	0.1%	
FIXED COST ELEMENTS				
Equipment Cost	$19.73	$19,732	15.0%	$98,661
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$1.25	$1,250	1.0%	$25,000
Maintenance Cost	$9.89	$9,893	7.5%	
Overhead Labor Cost	$25.00	$25,0[illegible]	19.1%	
Cost of Capital	$8.76	$8,[illegible]64	6.7%	
TOTAL FABRICATION COST	$131.22	$131,221	100.0%	$123,661

INTERMEDIATE CALCULATIONS

Process In Use	1.00	[1-Y 0-N]	PRO1
Cummulative Yield	66.2%		CYLD1
Effective Production Volume	1,511	/yr	ENUM1
Substrate Area	182.4	sq cm	AREA1
New Substrate Cost	$43.45	/pc	SUB1
Substrate Useful Life	1.00	cycle	LIFE1
Process Cycle Time	3	min/pc	CTIME1
Runtime for One Station	3%		RTIME1
Number of Parallel Stations	1.00		NSTAT1
Energy Requirement	0.959	kWh/pc	ENERGY1
Building Space/Station	250	sqft	SPACE1
Machine Cost	$65,774	/sta	MCH1
Machine Power	19.2	kW	POW1
Installed Equipment Cost	$88,795	/sta	IEQUIP1
Auxiliary Equipment Cost	$9,866	/sta	AEQUIP1
Equipment Annuity	$25,155	/yr	EINT1
Tooling Annuity	$0	/yr	TINT1
Building Annuity	$2,895	/yr	BINT1
Working Annuity	$103,171	/yr	WINT1

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DC ARC CVD TCM: DEPOSITION
IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$552.54	$552,543	25.0%	
Direct Labor Cost	$199.45	$199,449	9.0%	
Utility Cost	$212.38	$212,383	9.6%	
FIXED COST ELEMENTS				
Equipment Cost	$614.59	$614,593	27.8%	$3,072,964
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$30.00	$30,000	1.4%	$600,000
Maintenance Cost	$293.84	$293,837	13.3%	
Overhead Labor Cost	$80.00	$80,000	3.6%	
Cost of Capital	$230.75	$230,751	10.4%	
TOTAL FABRICATION COST	$2,213.56	$2,213,556	100.0%	$3,672,964

INTERMEDIATE CALCULATIONS

Process In Use	1.00	[1-Y 0-N]	PRO2
Cummulative Yield	69.7%		CYLD2
Effective Production Volume	1,436	/yr	ENUM2

ENERGY BALANCE CALCULATIONS

	H2	H	Ar	
Enthalpy Per Unit Mass	44,019	271,987	1,406	J/g
Molar Enthalpy	88,734	274,136	56,160	J/mol
Molar Entropy	202.79	162.59	202.72	J/K mol
Molar Heat Capacity (Cp)	37.11	20.79	20.79	J/K mol

Heat of Reaction (H2-->2H)	459,538	J/mol	
Entropy of Rxn (H2-->2H)	122	J/K mol	
Free Energy of Rxn (H2-->2H)	92,362	J/mol	
Equilibr Const Kp (H2-->2H)	2.47E-02		
Mole Fraction H	36.75%		
Mole Fraction Argon	27.21%		
Mole Fraction H2	36.04%		
Total Molar Enthalpy	148,004	J/mole	
Mean Molecular Weight	11.97	g/mole	
Mean Specific Enthalpy	12,369	J/g	
Mean Molar Heat Capacity	26.67	J/K mol	
Deposition Arc Power	80	kW	DAPOW2
Duct Area (A inf.)	60.80	sqcm	DCTAREA
Mass Flux	6.44	g/s	
Gas Velocity (U inf.)	33,113	cm/s	
Specific Heat Ratio (gamma)	1.45		
Speed of Sound	174,029	cm/s	

DC ARC CVD TCM: ETCHING
IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$3.98	$3,980	6.2%	
Direct Labor Cost	$4.62	$4,616	7.1%	
Utility Cost	$0.00	$0	0.0%	
FIXED COST ELEMENTS				
Equipment Cost	$1.80	$1,800	2.8%	$9,000
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$0.50	$500	0.8%	$10,000
Maintenance Cost	$1.52	$1,520	2.4%	
Overhead Labor Cost	$50.00	$50,000	77.4%	
Cost of Capital	$2.16	$2,157	3.3%	
TOTAL FABRICATION COST	$64.57	$64,574	100.0%	$19,000

INTERMEDIATE CALCULATIONS			
Process In Use	1.00	[1-Y 0-N]	PRO3
Cumulative Yield	79.6%		CYLD3
Effective Production Volume	1,256	/yr	ENUM3
Total Etched Thickness	3,810	um	ETHIK3
Average Etchant Rate	20.00	um/min	ERATE3
Process Cycle Time	0.18	hrs/pc	CTIME3
Runtime for One Station	9%		RTIME3
Number of Parallel Stations	1.00		NSTAT3
Chemical Requirement	$5.00	/pc	CHEM3
Energy Requirement	0	kWh/pc	ENERGY3
Building Space/Station	100	sq ft	SPACE3
Installed Equipment Cost	$8,100	/sta	IEQUIP3
Auxiliary Equipment Cost	$900	/sta	AEQUIP3
Equipment Annuity	$2,295	/yr	EINT3
Tooling Annuity	$0	/yr	TINT3
Building Annuity	$1,158	/yr	BINT3
Working Annuity	$61,121	/yr	WINT3

DC ARC CVD TCM: .SER TRIMMING
IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	0.0%	
Direct Labor Cost	$0.33	$331	0.6%	
Utility Cost	$0.00	$0	0.0%	
FIXED COST ELEMENTS				
Equipment Cost	$1.80	$1,800	3.2%	$9,000
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$0.50	$500	0.9%	$10,000
Maintenance Cost	$1.52	$1,520	2.7%	
Overhead Labor Cost	$50.00	$50,000	89.0%	
Cost of Capital	$2.02	$2,019	3.6%	
TOTAL FABRICATION COST	$56.17	$56,170	100.0%	$19,000

INTERMEDIATE CALCULATIONS			
Process In Use	1.00	[1-Y 0-N]	PRO4
Cumulative Yield	80.4%		CYLD4
Effective Production Volume	1,244	/yr	ENUM4
Process Cycle Time	0.01	hrs/pc	CTIME4
Runtime for One Station	1%		RTIME4
Number of Parallel Stations	1.00		NSTAT4
Energy Requirement	0	kWh/pc	ENERGY4
Building Space/Station	100	sq ft	SPACE4
Installed Equipment Cost	$8,100	/sta	IEQUIP4
Auxiliary Equipment Cost	$900	/sta	AEQUIP4
Equipment Annuity	$2,295	/yr	EINT4
Tooling Annuity	$0	/yr	TINT4
Building Annuity	$1,158	/yr	BINT4
Working Annuity	$52,717	/yr	WINT4

DC ARC CVD TCM: LAPPING

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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$725.01	$725,009	42.8%	
Direct Labor Cost	$586.32	$586,316	34.6%	
Utility Cost	$5.79	$5,786	0.3%	
FIXED COST ELEMENTS				
Equipment Cost	$14.33	$14,327	0.8%	$71,634
Tooling Cost	$74.41	$74,415	4.4%	$372,073
Building Cost	$8.00	$8,000	0.5%	$160,000
Maintenance Cost	$18.53	$18,531	1.1%	
Overhead Labor Cost	$200.00	$200,000	11.8%	
Cost of Capital	$60.58	$60,581	3.6%	
TOTAL FABRICATION COST	$1,692.97	$1,692,966	100.0%	$603,707

INTERMEDIATE CALCULATIONS			
Process In Use	1.00	[1=Y 0=N]	PRO5
Cumulative Yield	81.2%		CYLD5
Effective Production Volume	1,231	/yr	ENUM5
Thickness of Material Lapped	111.11	um	HLAP5
Setup Time	1.33	hrs/batch	CTIME5A
Lapping Time	111.11	hrs/batch	CTIME5B
Runtime for One Station	377%		RTIME5
Number of Parallel Stations	4.00		NSTAT5
Lapping Plate Cost	$869	/ea	PLA5
Lapping Plate Life	14	pcs	WHEEL5
Number of Plates Required	428.00		PLAT5
Lapping Slurry Consumption	11.11	l/pc	GRIT5
Machine Power	4.2	kW	PWR5
Energy Requirement	94	kWh/pc	ENERGY5
Machine Cost	$11,939	/sta	MCH5
Building Space/Station	400	sq ft	SPACE5
Installed Equipment Cost	$16,118	/sta	IEQUIP5
Auxiliary Equipment Cost	$1,791	/sta	AEQUIP5
Equipment Annuity	$18,264	/yr	EINT5
Tooling Annuity	$94,865	/yr	TINT5
Building Annuity	$18,528	/yr	BINT5
Working Annuity	$1,561,308	/yr	WINT5

DC ARC CVD TCM: INSPECTION - MICROSCOPY

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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	0.0%	
Direct Labor Cost	$5.25	$5,249	6.4%	
Utility Cost	$0.00	$1	0.0%	
FIXED COST ELEMENTS				
Equipment Cost	$15.00	$15,000	18.2%	$75,000
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$0.25	$250	0.3%	$5,000
Maintenance Cost	$6.40	$6,400	7.8%	
Overhead Labor Cost	$50.00	$50,000	60.7%	
Cost of Capital	$5.48	$5,482	6.7%	
TOTAL FABRICATION COST	$82.38	$82,382	100.0%	$80,000

INTERMEDIATE CALCULATIONS			
Process In Use	1.00	[1=Y 0=N]	PRO6
Cumulative Yield	90.3%		CYLD6
Effective Production Volume	1,108	/yr	ENUM6
Process Cycle Time	0.25	hrs	CTIME6
Runtime for One Station	10%		RTIME6
Number of Parallel Stations	1.00		NSTAT6
Energy Requirement	0	kWh/pc	ENERGY6
Building Space/Station	50	sq ft	SPACE6
Installed Equipment Cost	$67,500	/sta	IEQUIP6
Auxiliary Equipment Cost	$7,500	/sta	AEQUIP6
Equipment Annuity	$19,122	/yr	EINT6
Tooling Annuity	$0	/yr	TINT6
Building Annuity	$579	/yr	BINT6
Working Annuity	$62,680	/yr	WINT6

DC ARC CVD TCM: INSPECTION - THERMAL CONDUCTIVITY
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	0.0%	
Direct Labor Cost	$4.99	$4,986	6.1%	
Utility Cost	$0.00	$1	0.0%	
FIXED COST ELEMENTS				
Equipment Cost	$15.00	$15,000	18.3%	$75,000
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$0.25	$250	0.3%	$5,000
Maintenance Cost	$6.40	$6,400	7.8%	
Overhead Labor Cost	$50.00	$50,000	60.9%	
Cost of Capital	$5.48	$5,477	6.7%	
TOTAL FABRICATION COST	$82.11	$82,115	100.0%	$80,000

INTERMEDIATE CALCULATIONS

Process In Use	1.00	[1=Y 0=N]	PRO7
Cumulative Yield	95.0%		CYLD7
Effective Production Volume	1,053	/yr	ENUM7
Process Cycle Time	0.25	hrs	CTIME7
Runtime for One Station	10%		RTIME7
Number of Parallel Stations	1.00		NSTAT7
Energy Requirement	0	kWh/pc	ENERGY7
Building Space/Station	50	sq ft	SPACE7
Installed Equipment Cost	$67,500	/sta	IEQUIP7
Auxiliary Equipment Cost	$7,500	/sta	AEQUIP7
Equipment Annuity	$19,122	/yr	EINT7
Tooling Annuity	$0	/yr	TINT7
Building Annuity	$579	/yr	BINT7
Working Annuity	$62,413	/yr	WINT7

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DC ARC CVD TCM: COST SUMMARY
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$1,347.19	$1,347,192	31.2%	
Direct Labor Cost	$801.80	$801,797	18.5%	
Utility Cost	$218.24	$218,245	5.0%	
FIXED COST ELEMENTS				
Equipment Cost	$682.25	$682,252	15.8%	$3,411,259
Tooling Cost	$74.41	$74,415	1.7%	$372,073
Building Cost	$40.75	$40,750	0.9%	$815,000
Maintenance Cost	$338.10	$338,101	7.8%	
Overhead Labor Cost	$505.00	$505,000	11.7%	
Cost of Capital	$315.23	$315,232	7.3%	
TOTAL FABRICATION COST	$4,322.98	$4,322,983	100.0%	$4,598,332

SUMMARY INFORMATION

Part Name	6 in. substrate	
Total Direct Laborers	10.10	/shift
Total Floor Space	8,150	sqft
Total Capital Investment	$4.6	MM
Area Cost	$23.70	/sqcm
Cost Per Carat	$13.50	/ct

Operation	Equipment	Material	Labor	Other
Surface Preparation	$20	$66	$26	$20
Deposition	$615	$553	$279	$767
Etching	$2	$4	$55	$4
Laser Trimming	$2	$0	$50	$4
Lapping	$14	$725	$786	$167
Inspect - Microscopy	$15	$0	$55	$12
Inspect - Thermal Cond'vity	$15	$0	$55	$12
Total	$682	$1,347	######	$987
Total =	$4,323			

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Appendix B

MICROWAVE CVD DIAMOND TECHNICAL COST MODEL
IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

Revision Date: 8/10/93

PRODUCT SPECIFICATIONS

Part Name	6 in. substrate		NAME
Wafer Diameter	15.24	cm	DIAM
Finished Wafer Thickness	1,000	um	THIK
Annual Production Volume	1	(000/yr)	NUM
Length of Production Run	5	yrs	PLIFE

PROCESS RELATED FACTORS - SURFACE PREPARATION

Process In Use?	1.00	[1=Y 0=N]	USE1
Dedicated Investment	1.00	[1=Y 0=N]	DED1
Process Yield	95.0%		YLD1
Average Equipment Downtime	20.0%		DOWN1
Direct Laborers Per Station	0.50		NLAB1
Substrate Material	37	[menu #]	MATL1
Pieces Per Batch	20.00	pcs/batch	PCS1
Process Time	60.00	min/batch	PTIME1
Building Space Requirement	250	sqft/sta	FLR1

PROCESS RELATED FACTORS - DEPOSITION

Process In Use?	1.00	[1=Y 0=N]	USE2
Dedicated Investment	1.00	[1=Y 0=N]	DED2
Process Yield	90.0%		YLD2
Average Equipment Downtime	15.0%		DOWN2
Direct Laborers	0.20	/sta	NLAB2

	Menu #	vol%	
Hydrogen	9	88.7%	GASA VOLA
Carbon Containing Gas	16	10.0%	GASB VOLB
Carrier Gas	0	0.0%	GASC VOLC
Other Gas	25	1.3%	GASD VOLD
		100.0%	

Hydrogen Recycle Rate	0.0%		RECYC
Carrier Gas Recycle Rate	0.0%		RECYC2
Gas Recycle Equipment Cost	$250,000	total	MCH2A
Machine Power	250	kW	POW2
Carbon Capture Factor	15.0%		CCF2
Machine Load/Unload Time	30.00	min/batch	PTIME2
Available Deposition Time	8,640	hrs/yr	DAYHR2
Microwave Tube Life	3000	hrs	LIFE2
Coolant Temp. Rise	50.00	C	TEMP2
Heat Capacity of Coolant	1.0	cal/g/C	CP2
Building Space Requirement	400	sqft/sta	FLR2

MICROWAVE CVD DIAMOND TECHNICAL COST MODEL
IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

GAS DATABASE

#	Gas	Source	Purity	Price $/SCM	No. of Carbons	Liq Gas	Tank gal	Price Update
0	None			$0.00	0.00	0.00		
1	Liq Hydrogen	Airco	99.998%	$0.34	0.00	1.00	6000	1/93
2	Liq Hydrogen	Airco	99.998%	$0.32	0.00	1.00	11000	1/93
3	Liq Hydrogen	Airco	99.998%	$0.30	0.00	1.00	20000	1/93
4	Liq Argon	Airco	99.998%	$1.41	0.00	1.00	3000	1/93
5	Liq Argon	Airco	99.998%	$1.32	0.00	1.00	6000	1/93
6	Liq Argon	Airco	99.998%	$1.29	0.00	1.00	11000	1/93
7	Hydrogen	MG Ind.	99.9999%	$29.86	0.00	0.00		1/93
8	Hydrogen	MG Ind.	99.9996%	$40.61	0.00	0.00		1/93
9	Hydrogen	MG Ind.	99.999%	$10.28	0.00	0.00		1/93
10	Hydrogen	Air Prod.	99.95%	$1.59	0.00	0.00		1/93
11	Argon	MG Ind.	99.9999%	$33.09	0.00	0.00		1/93
12	Argon	Air Prod.	99.9997%	$37.33	0.00	0.00		1/93
13	Argon	Air Prod.	99.999%	$11.74	0.00	0.00		1/93
14	Argon	Air Prod.	99.997%	$2.03	0.00	0.00		1/93
15	Methane	Air Prod.	99.99%	$21.99	1.00	0.00		1/93
16	Methane	Air Prod.	99%	$13.76	1.00	0.00		1/93
17	Methane	Air Prod.	93%	$4.93	1.00	0.00		1/93
18	Acetylene	Air Prod.	99.6%	$6.80	2.00	0.00		1/93
19	Acetylene	Air Prod.	98%	$5.85	2.00	0.00		1/93
20	Helium	Air Prod.	99.9995%	$15.90	0.00	0.00		1/93
21	Helium	Air Prod.	99.995%	$4.77	0.00	0.00		1/93
22	Nitrogen	Air Prod.	99.9996%	$45.50	0.00	0.00		1/93
23	Nitrogen	MG Ind.	99.999%	$9.23	0.00	0.00		1/93
24	Nitrogen	Air Prod.	99.998%	$1.24	0.00	0.00		1/93
25	Oxygen	Air Prod.	99.998%	$2.00	0.00	0.00		1/93
26								

SUBSTRATE DATABASE

#	Substrate	Source	Price $/ea	Thick um	Diam cm	Etch um/min	Life use#	Price Update
0	None		$0.00	1	1.00	1.00	1.00	
1	Silicon	Si-Tech	$2.65	1270.00	5.08	20.00	1	1/93
2	Silicon	Si-Tech	$3.50	1270.00	7.62	20.00	1	1/93
3	Silicon	Si-Tech	$6.25	1270.00	10.16	20.00	1	1/93
4	Silicon	Si-Tech	$9.70	1270.00	12.70	20.00	1	1/93
5	Silicon	Si-Tech	$18.60	1270.00	15.24	20.00	1	1/93
6	Silicon	Si-Tech	$57.95	1270.00	20.32	20.00	1	1/93
7	Silicon	Si-Tech	$4.35	3810.00	5.08	20.00	1	1/93
8	Silicon	Si-Tech	$8.15	3810.00	7.62	20.00	1	1/93
9	Silicon	Si-Tech	$14.50	3810.00	10.16	20.00	1	1/93
10	Silicon	Si-Tech	$22.65	3810.00	12.70	20.00	1	1/93

PROCESS RELATED FACTORS - ETCHING

Process In Use?	0.00	[1=Y 0=N]	USE3
Dedicated Investment	1.00	[1=Y 0=N]	DED3
Process Yield	99.0%		YLD3
Average Equipment Downtime	10.0%		DOWN3
Direct Laborers Per Station	1.00		NLAB3
Load/Unload and Rinse Time	30.00	min/batch	PTIME3
Pieces Per Batch	20.00		PCS3
Machine Cost	$6,000	/sta	MCH3
Etchant Cost	$70	/liter	ETCH3A
Etchant Disposal Cost	$30	/liter	ETCH3B
Machine Etchant Capacity	1.00	l/batch	CAP3
Machine Power	0.00	kW	POW3
Building Space Requirement	100	sqft/sta	FLR3

PROCESS RELATED FACTORS - LASER TRIMMING

Process In Use?	1.00	[1=Y 0=N]	USE4
Dedicated Investment	1.00	[1=Y 0=N]	DED4
Process Yield	99.0%		YLD4
Average Equipment Downtime	10.0%		DOWN4
Direct Laborers Per Station	1.00		NLAB4
Machine Cost	$6,000	/sta	MCH4
Trimming Rate	1.00	cm/s	RATE4
Machine Power	5.00	kW	POW4
Building Space Requirement	100	sqft/sta	FLR4

PROCESS RELATED FACTORS - LAPPING

Process In Use?	1.00	[1=Y 0=N]	USE5
Dedicated Investment	1.00	[1=Y 0=N]	DED5
Process Yield	90.0%		YLD5
Average Equipment Downtime	15.0%		DOWN5
Direct Laborers Per Station	0.25		NLAB5
Lapped Material Removal	10.0%	by wgt	TLAP5
No of Lapping Steps	2.00		LAPS5
Pieces Per Batch	5.00		PCS5
Load/Unload and Clean Wafers	40.00	min/batch	PTIME5
Average Lapping Rate	1.0	um/hr	RATE5
Lapping Slurry Cost	$53	/liter	LAPSL5
Lapping Slurry Usage Rate	0.50	liter/hr	LAPR5
Lapping Plate Life	320.00	hrs	PLAL5
Available Lapping Time	8,640	hrs/yr	DAYHR5
Building Space Requirement	400	sqft/sta	FLR5

PROCESS RELATED FACTORS - HOT IRON POLISH

Process In Use?	0.00	[1=Y 0=N]	USE6
Dedicated Investment	1.00	[1=Y 0=N]	DED6
Process Yield	90.0%		YLD6

11	Silicon	Si-Tech	$43.45	3810.00	15.24	20.00	1	1/93
12	Silicon	Si-Tech	$135.20	3810.00	20.32	20.00	1	1/93
13	Silicon	Si-Tech	$6.85	6350.00	5.08	20.00	1	1/93
14	Silicon	Si-Tech	$12.80	6350.00	7.62	20.00	1	1/93
15	Silicon	Si-Tech	$22.75	6350.00	10.16	20.00	1	1/93
16	Silicon	Si-Tech	$35.55	6350.00	12.70	20.00	1	1/93
17	Silicon	Si-Tech	$68.30	6350.00	15.24	20.00	1	1/93
18	Silicon	Si-Toch	$212.45	6350.00	20.32	20.00	1	1/93
19	Molybdenum	Phil. Elmet	$3.90	254	5.08	10.00	1	1/93
20	Molybdenum	Phil. Elmet	$8.20	254	10.16	10.00	1.00	1/93
21	Molybdenum	Phil. Elmet	$14.50	254	15.24	10.00	1.00	1/93
22	Molybdenum	logies Corp	$25.35	254	20.32	10.00	1.00	1/93
23	Molybdenum	logies Corp	$4.80	508.00	5.08	10.00	4	1/93
24	Molybdenum	logies Corp	$14.75	508.00	10.16	10.00	4	1/93
25	Molybdenum	logies Corp	$24.30	508.00	15.24	10.00	4	1/93
26	Molybdenum	logies Corp	$37.10	508.00	20.32	10.00	4	1/93
27	Molybdenum	Phil. Elmet	$9.15	1524.00	5.08	10.00	20	1/93
28	Molybdenum	logies Corp	$27.60	1524.00	10.16	10.00	20	1/93
29	Molybdenum	logies Corp	$52.25	1524.00	15.24	10.00	20	1/93
30	Molybdenum	logies Corp	$85.25	1524.00	20.32	10.00	20	1/93
31	Molybdenum	logies Corp	$14.75	2286.00	5.08	10.00	32.00	1/93
32	Molybdenum	logies Corp	$36.00	2286.00	10.16	10.00	32.00	1/93
33	Molybdenum	logies Corp	$69.00	2286.00	15.24	10.00	32.00	1/93
34	Molybdenum	logies Corp	$113.50	2286.00	20.32	10.00	32.00	1/93
35	Molybdenum	logies Corp	$18.50	3175.00	5.08	10.00	46.00	1/93
36	Molybdenum	logies Corp	$46.75	3175.00	10.16	10.00	46.00	1/93
37	Molybdenum	logies Corp	$90.50	3175.00	15.24	10.00	46.00	1/93
38	Molybdenum	logies Corp	$149.00	3175.00	20.32	10.00	46.00	1/93
39	Tungsten	logies Corp	$7.75	254	5.08	10.00	1	1/93
40	Tungsten	logies Corp	$24.50	254	10.16	10.00	1.00	1/93
41	Tungsten	logies Corp	$50.00	254	15.24	10.00	1.00	1/93
42	Tungsten	logies Corp	$79.25	254	20.32	10.00	1.00	1/93
43	Tungsten	logies Corp	$10.00	508.00	5.08	10.00	4.00	1/93
44	Tungsten	logies Corp	$35.10	508.00	10.16	10.00	4.00	1/93
45	Tungsten	logies Corp	$67.00	508.00	15.24	10.00	4.00	1/93
46	Tungsten	logies Corp	$109.20	508.00	20.32	10.00	4.00	1/93
47	Tungsten	logies Corp	$50.00	1524.00	5.08	10.00	20.00	1/93
48	Tungsten	logies Corp	$112.00	1524.00	10.16	10.00	20.00	1/93
49	Tungsten	logies Corp	$317.00	1524.00	15.24	10.00	20.00	1/93
50	Tungsten	logies Corp	$422.00	1524.00	20.32	10.00	20.00	1/93
51	Tungsten	logies Corp	$60.00	3175.00	5.08	10.00	46.00	1/93
52	Tungsten	logies Corp	$161.25	3175.00	10.16	10.00	46.00	1/93
53	Tungsten	logies Corp	$521.30	3175.00	15.24	10.00	46.00	1/93
54	Tungsten	logies Corp	$687.00	3175.00	20.32	10.00	46.00	1/93
55								

TARGET DATABASE #	Metal	Vendor	Price $/g	Dep.Rt. A/kWm	Density g/cc			Price Update
0	None		$0	##########	1.00			
1	Titanium	Tosoh	$1.90	80.00	4.51			1/93
2	Platinum	Tosoh	$19.00	125.00	21.45			1/93
3	Gold	Tosoh	$17.00	230.00	19.32			1/93
4	Silver	Tosoh	$2.45	215.00	10.50			1/93
5	Copper	Tosoh	$1.15	210.00	8.96			1/93

Average Equipment Downtime	15.0%		DOWN6
Direct Laborers Per Station	0.25		NLAB6
Material Removed	10.0%	by wgt	TLAP6
No of Polishing Steps	1.00		LAPS6
Pieces Per Batch	5.00		PCS6
Load/Unload and Clean Wafers	40.00	min/batch	PTIME6
Average Polishing Rate	5.000	um/hr	RATE6
Useful Polishing Plate Life	10.00	cycles	PLAL6
Available Polishing Time	8,640	hrs/yr	DAYHR6
Building Space Requirement	400	sqft/sta	FLR6

PROCESS RELATED FACTORS - OXYGEN PLASMA POLISHING

Process In Use?	0.00	[1=Y 0=N]	USE7
Dedicated Investment	1.00	[1=Y 0=N]	DED7
Process Yield	90.0%		YLD7
Average Equipment Downtime	15.0%		DOWN7
Direct Laborers Per Station	0.25		NLAB7

	Menu #	vol%	
Oxygen	25	100.0%	GAS7A VOL7A
Argon	0	0.0%	GAS7B VOL7B
Other Gas	0	0.0%	GAS7C VOL7C
		100.0%	

Material Removed	10.0%	by wgt	TLAP7
No of Polishing Steps	1.00		LAPS7
Pieces Per Batch	1.00		PCS7
Oxygen Gas Consumption	500.00	sccm	TFLOW7
Load/Unload and Clean Wafers	40.00	min/batch	PTIME7
Average Polishing Rate	3.300	um/hr	RATE7
Machine Power	10.00	kW	POW7
Machine Cost	$300,000	/sta	MCH7
Available Polishing Time	8,640	hrs/yr	DAYHR7
Building Space Requirement	400	sqft/sta	FLR7

PROCESS RELATED FACTORS - OXYGEN ION MILLING

Process In Use?	0.00	[1=Y 0=N]	USE8
Dedicated Investment	1.00	[1=Y 0=N]	DED8
Process Yield	90.0%		YLD8
Average Equipment Downtime	15.0%		DOWN8
Direct Laborers Per Station	0.25		NLAB8

	Menu #	vol%	
Oxygen	25	100.0%	GAS8A VOL8A
Argon	4	0.0%	GAS8B VOL8B
Other Gas	0	0.0%	GAS8C VOL8C

6	Nickel	Tosoh	$0.95	30.00	8.91	1/93
7	Palladium	Tosoh	$8.45	210.00	12.02	1/93
8	Silicon	Tosoh	$0.80	15.00	2.33	1/93

EVAPORATION DATABASE

#	Metal	Vendor	Price $/g	Dep.Rt. A/kWm	Density g/cc	Price Update
0	None		$0	##########	1.00	
1	Titanium	re Tech Inc	$4.40	9,520.00	4.51	1/93
2	Platinum	re Tech Inc	$18.59	6,428.57	21.45	1/93
3	Gold	re Tech Inc	$14.58	6,428.57	19.32	1/93
4	Silver	re Tech Inc	$3.12	215.00	10.50	1/93
5	Copper	re Tech Inc	$1.08	210.00	8.96	1/93
6	Nickel	re Tech Inc	$1.49	30.00	8.91	1/93
7	Palladium	re Tech Inc	$7.03	210.00	12.02	1/93
8	Silicon	re Tech Inc	$7.51	15.00	2.33	1/93
####	###########	###########	########	##########	########	####### ###### #######

100.0%

Material Removed	10.0%	by wgt	TLAP8
No of Polishing Steps	1.00		LAPS8
Pieces Per Batch	3.00		PCS8
Oxygen Gas Consumption	10.00	sccm	TFLOW8
Ion Source Life	1,000	hrs	SOUL8
Ion Source Cost	$1,000	/ea	SCOST8
Load/Unload and Clean Wafers	40.00	min/batch	PTIME8
Preheat Time	5.00	min	PREHT8
Linear Polishing Rate	0.240	um/hr	RATE8
Machine Power	1.00	kW	POW8
Machine Cost	$500,000	/sta	MCH8
Available Polishing Time	8,640	hrs/yr	DAYHR8
Building Space Requirement	400	sqft/sta	FLR8

PROCESS RELATED FACTORS - METALLIZATION - SPUTTERING

Process In Use?	1.00	[1=Y 0=N]	USE9
Dedicated Investment	1.00	[1=Y 0=N]	DED9
Process Yield	99.0%		YLD9
Average Equipment Downtime	20.0%		DOWN9
Direct Laborers Per Station	0.10		NLAB9
Load/Unload Laborers	1.00		LLAB9

Metal Layers	Menu #		Thick (um)	
Titanium	1	MET9A	0.10	THK9A
Platinum	2	MET9B	0.10	THK9B
Gold	3	MET9C	0.10	THK9C

Load Time	15	min/batch	PTIME9
Target Preheat Time	1	min/kW	HTIME9
Pieces Per Batch	3	pcs/batch	PCS9
Metallization Magnetron Power	3	kW	POW9
Building Space Requirement	400	sqft/sta	FLR9

PROCESS RELATED FACTORS - METALLIZATION - EVAPORATION

Process In Use?	0.00	[1=Y 0=N]	USE10
Dedicated Investment	1.00	[1=Y 0=N]	DED10
Process Yield	99.0%		YLD10
Average Equipment Downtime	20.0%		DOWN10
Direct Laborers Per Station	0.10		NLAB10
Load/Unload Laborers	1.00		LLAB10

Metal Layers	Menu #		Thick (um)	
Titanium	1	MET10A	0.10	THK10A
Platinum	2	MET10B	0.10	THK10B
Gold	3	MET10C	0.10	THK10C

Load Time	15	min/batch	PTIME10
Target Preheat Time	1.00	min/kW	HTIME10
Pieces Per Batch	5.00	pcs/batch	PCS10
Evaporator Power	7.00	kW	POW10
Building Space Requirement	400	sqft/sta	FLR10
Percent Inspection	100%		INSP10

PROCESS RELATED FACTORS - INSPECTION - MICROSCOPY

Process In Use?	1.00	[1=Y 0=N]	USE11
Dedicated Investment	1.00	[1=Y 0=N]	DED11
Process Yield	95.0%		YLD11
Average Equipment Downtime	5.0%		DOWN11
Direct Laborers Per Station	1.00		NLAB11
Average Inspection Time	15.00	min/batch	PTIME11
Percent Inspection	100%		INSP11
Machine Cost	$50,000	/sta	MCH11
Machine Power	0.10	kW	POW11
Building Space Requirement	50	sqft/sta	FLR11

PROCESS RELATED FACTORS - INSPECTION - THERMAL CONDUCTIVITY

Process In Use?	1.00	[1=Y 0=N]	USE12
Dedicated Investment	1.00	[1=Y 0=N]	DED12
Process Yield	95.0%		YLD12
Average Equipment Downtime	5.0%		DOWN12
Direct Laborers Per Station	1.00		NLAB12
Average Inspection Time	15.00	min/batch	PTIME12
Percent Inspection	100%		INSP12
Machine Cost	$50,000	/sta	MCH12
Machine Power	0.10	kW	POW12
Building Space Requirement	50	sqft/sta	FLR12

OPTIONAL INPUTS

	override	estimate		
Surface Preparation				
Machine Cost	$0	$65,774	/sta	OMCH1
Machine Power	0.0	19.2	kW	OPOW1
Deposition				
Deposition Rate	0.00	3.25	g/hr	ODRATE2
Deposition Equipment Cost	$0	$1,829	k$/sta	OMCH2
Microwave Tube Cost	$0	$25,977	/sta	OTUBE2
Etching				
Process Cycle Time	0.00	0.29	hrs	OCTIME3
Chemical Requirement	$0	$5.00	/pc	OCHEM3
Laser Trimming				
Process Cycle Time	0.00	0.01	hrs	OCTIME4
Lapping				
Lapping Time	0.00	111.11	hrs	OCTIME5
Lapping Plate Cost	$0	$869	/ea	OWHEEL5

Lapping Machine Cost	$0	$11,939	/sta	OMCH5
Lapping Machine Power	0.00	4.2	kW	OPWR5
Hot Iron Polish				
Lapping Time	0.00	34.34	hrs	OCTIME6
Lapping Plate Cost	$0	$784	/ea	OWHEEL6
Machine Cost	$0	$11,939	/sta	OMCH6
Lapping Machine Power	$0	45.84	kW	OPWR6
Oxygen Plasma Polishing				
Process Cycle Time	0.00	34.34	hrs	OCTIME7
Oxygen Ion Milling				
Process Cycle Time	0.00	154.57	hrs	OCTIME8
Metallization-Sputtering				
Process Cycle Time	0.00	0.29	hrs	OSPUT9
Machine Cost	$0	$225,516		OMCH9
Metallization-Evaporation				
Process Cycle Time	0.00	#VALUE!	hrs	OCTIME10
Metallization Time	0.00	0.07	hrs	OEVAP10

EXOGENOUS COST FACTORS

Direct Wages	$13.33	/hr	WAGE	
Indirect Salary	$50,000	/yr	SALARY	* exc. dep. & lap
Indirect:Direct Labor Ratio	1.00		ILAB	
Benefits on Wage and Salary	35.0%		BENI	
Working Days per Year	360.00		DAYS	
Working Hours per Day (*)	8.00	/hr	HRS	
Capital Recovery Rate	10%		CRR	
Capital Recovery Period	5.00	yrs	ELIFE	
Building Recovery Life	20.00	yrs	BLIFE	
Working Capital Period	3.00	months	WCP	
Price of Electricity	$0.050	/kWh	ELEC	
Price of Natural Gas	$6.50	/MBTU	GAS	
Price of Building Space	$100	/sqft	PBLD	
Price of Cooling Water	$0.03	/100 gal	WATER	
Auxiliary Equipment Cost	15.0%		AUX	
Equipment Installation Cost	35.0%		INST	
Maintenance Cost	8.0%		MNT	

REGRESSION CONSTANTS, COEFFICIENTS, AND EXPONENTS

-Surface Preparation-		
Machine Cost Constant	1,334	MCH1A
Machine Cost Capacity Coef	3,222	MCH1B
Machine Power Constant	-0.75	PWR1A
Machine Power Capacity Coef	1.00	PWR1B
-Deposition-		
Deposition Rate Constant	0.013	CYC2
Machine Cost Power Coef	68,276	MCH2Y
Machine Cost Power Exponent	0.58	MCH2Z
Machine Cost Power Constant	150,000	MCH2X
Tube Cost Constant	1724	TUBE2Y
Tube Cost Coef	97.01	TUBE2Z

Tank 1 $ Capacity Constant	1,175	TANK2A
Tank 1 $ Capacity Coef	0.165	TANK2B
Tank 2 $ Capacity Constant	370.00	TANK2X
Tank 2 $ Capacity Coef	0.03	TANK2Y
-Etching-		
-Lapping-		
Machine Cost Constant	2,719	MCH5A
Machine Cost Capacity Coef	1,844	MCH5B
Machine Power Constant	-0.75	PWR5A
Machine Power Capacity Coef	1.00	PWR5B
Tool Cost Constant	771.00	TOOL5A
Tool Cost Capacity Coef	0.92	TOOL5B
Tool Cost Capacity Exponent	2.90	TOOL5C
-Hot Iron Polish-		
Machine Cost Constant	21,752	MCH6A
Machine Cost Capacity Coef	14,752	MCH6B
Machine Power Constant	6.00	PWR6A
Machine Power Capacity Coef	7.97	PWR6B
Tool Cost Constant	771.00	TOOL6A
Tool Cost Capacity Coef	0.92	TOOL6B
Tool Cost Capacity Exponent	2.90	TOOL6C
--Metallization-Sputtering-		
Machine Cost Constant	160,720.00	MCH9A
Machine Cost Capacity Coef1	129.43	MCH9B
Machine Cost Capacity Coef2	-0.02	MCH9C
Machine Cost Capacity Coef2	0.00	MCH9D
-Metallization-Evaporation-		
Machine Cost Constant	367,070.00	MCH10A
Machine Cost Capacity Coef1	(3,797.80)	MCH10B
Machine Cost Capacity Coef2	22.02	MCH10C
Machine Cost Capacity Coef3	(0.05)	MCH10D
Machine Cost Capacity Coef4	0.00	MCH10E

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MICROWAVE CVD TCM: SURFACE PREPARATION
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$2.89	$2,890	4.3%	
Direct Labor Cost	$0.83	$826	1.2%	
Utility Cost	$0.07	$70	0.1%	
FIXED COST ELEMENTS				
Equipment Cost	$19.73	$19,732	29.3%	$98,661
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$1.25	$1,250	1.9%	$25,000
Maintenance Cost	$9.89	$9,893	14.7%	
Overhead Labor Cost	$25.00	$25,000	37.1%	
Cost of Capital	$7.71	$7,714	11.4%	
TOTAL FABRICATION COST	$67.38	$67,377	100.0%	$123,661

INTERMEDIATE CALCULATIONS

Process In Use	1.00	[1=Y 0=N]	PRO1
Cummulative Yield	68.1%		CYLD1
Effective Production Volume	1,469	/yr	ENUM1
Substrate Area	182.4	sq cm	AREA1
New Substrate Cost	$90.50	/pc	SUB1
Substrate Useful Life	46.00	cycle	LIFE1
Process Cycle Time	3	min/pc	CTIME1
Runtime for One Station	3%		RTIME1
Number of Parallel Stations	1.00		NSTAT1
Energy Requirement	0.959	kWh/pc	ENERGY1
Building Space/Station	250	sqft	SPACE1
Machine Cost	$65,774	/sta	MCH1
Machine Power	19.2	kW	POW1
Installed Equipment Cost	$88,795	/sta	IEQUIP1
Auxiliary Equipment Cost	$9,866	/sta	AEQUIP1
Equipment Annuity	$25,155	/yr	EINT1
Tooling Annuity	$0	/yr	TINT1
Building Annuity	$2,895	/yr	BINT1
Working Annuity	$39,327	/yr	WINT1

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MICROWAVE CVD TCM: DEPOSITION
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$142.30	$142,304	2.4%	
Direct Labor Cost	$132.72	$132,721	2.3%	
Utility Cost	$393.42	$393,424	6.8%	
FIXED COST ELEMENTS				
Equipment Cost	$2,743.63	$2,743,631	47.2%	$13,718,155
Tooling Cost	$337.69	$337,695	5.8%	$1,688,473
Building Cost	$10.00	$10,000	0.2%	$200,000
Maintenance Cost	$1,113.45	$1,113,452	19.2%	
Overhead Labor Cost	$50.00	$50,000	0.9%	
Cost of Capital	$890.59	$890,595	15.3%	
TOTAL FABRICATION COST	$5,813.82	$5,813,821	100.0%	$15,606,627

INTERMEDIATE CALCULATIONS

Process In Use	1.00	[1=Y 0=N]	PRO2	
Cummulative Yield	71.6%		CYLD2	
Effective Production Volume	1,396	/yr	ENUM2	
Mass of Diamond Deposited	71.34	g	MASS2	
Mass Deposition Rate	3.25	g/hr	MASDEP2	
Linear Deposition Rate	51	um/hr	LINDEP2	
Deposition Time	21.95	hrs	CTIMEB2	
Machine Setup Time	0.50	hrs	CTIMEA2	
Runtime for One Station	427%		RTIME2	
Number of Parallel Stations	5.00		NSTAT2	
Total Carbon Gas Volume	0.97	SCM	CARGAS2	
Total Gas Volume	10	SCM	TVOL2	
Total Gas Flow Rate	7,358	sccm	FLOWR2	
	Consumption (SCM/pc)	Cost ($/pc)		
Hydrogen Consumption	8.60	$123.34	GASA2	COSTA2
Carbon Gas Consumption	0.97	$18.61	GASB2	COSTB2
Carrier Gas Consumption	0.00	$0.00	GASC2	COSTC2
Other Gas Consumption	0.13	$0.35	GASD2	COSTD2
Energy Requirement	5,488	kWh/pc	ENERGY2	
Physical Tube Life	0.41	years	TLIFE2	
Number of Tubes per Station	13.00		NTUBE2	
New Microwave Tube Cost	$25,977	/tube	TUBE2	

Cooling Water Flow Rate	18.9	gal/min	WATER2
Cooling Water Requirement	24,927	gal/pc	COOL2
Building Space/Station	400	sqft	SPACE2
Recycle Equipment Cost	$0	/sta	REC2
Liquid Hydrogen Tank Rental	$0	/mo/tank	HYD2
Liq Carrier Gas Tank Rental	$0	/mo/tank	CAR2
Gas Storage Equipment Rent	$0	/year	GTANK2
Machine Cost	$1,829,087	/sta	MCH2B
Installed Equipment Cost	$2,469,268	/sta	IEQUIP2
Auxiliary Equipment Cost	$274,363	/sta	AEQUIP2
Equipment Annuity	$3,497,643	/yr	EINT2
Tooling Annuity	$430,501	/yr	TINT2
Building Annuity	$23,161	/yr	BINT2
Working Annuity	$1,862,517	/yr	WINT2

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MICROWAVE CVD TCM: ETCHING
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	#DIV/0!	
Direct Labor Cost	$0.00	$0	#DIV/0!	
Utility Cost	$0.00	$0	#DIV/0!	
FIXED COST ELEMENTS				
Equipment Cost	$0.00	$0	#DIV/0!	$0
Tooling Cost	$0.00	$0	#DIV/0!	$0
Building Cost	$0.00	$0	#DIV/0!	$0
Maintenance Cost	$0.00	$0	#DIV/0!	
Overhead Labor Cost	$0.00	$0	#DIV/0!	
Cost of Capital	$0.00	$0	#DIV/0!	
TOTAL FABRICATION COST	$0.00	$0	#DIV/0!	$0

INTERMEDIATE CALCULATIONS			
Process In Use	0.00	[1=Y 0=N]	PRO3
Cumulative Yield	79.6%		CYLD3
Effective Production Volume	1,256	/yr	ENUM3
Total Etched Thickness	3,175	um	ETHIK3
Average Etchant Rate	10.00	um/min	ERATE3
Process Cycle Time	0.29	hrs/pc	CTIME3
Runtime for One Station	14%		RTIME3
Number of Parallel Stations	1.00		NSTAT3
Chemical Requirement	$5.00	/pc	CHEM3
Energy Requirement	0	kWh/pc	ENERGY3
Building Space/Station	100	sq ft	SPACE3
Installed Equipment Cost	$8,100	/sta	IEQUIP3
Auxiliary Equipment Cost	$900	/sta	AEQUIP3
Equipment Annuity	$0	/yr	EINT3
Tooling Annuity	$0	/yr	TINT3
Building Annuity	$0	/yr	BINT3
Working Annuity	$0	/yr	WINT3

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MICROWAVE CVD TCM: .SER TRIMMING
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	0.0%	
Direct Labor Cost	$0.33	$334	0.6%	
Utility Cost	$0.00	$4	0.0%	
FIXED COST ELEMENTS				
Equipment Cost	$1.80	$1,800	3.2%	$9,000
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$0.50	$500	0.9%	$10,000
Maintenance Cost	$1.52	$1,520	2.7%	
Overhead Labor Cost	$50.00	$50,000	89.0%	
Cost of Capital	$2.02	$2,019	3.6%	
TOTAL FABRICATION COST	$56.18	$56,178	100.0%	$19,000

INTERMEDIATE CALCULATIONS			
Process In Use	1.00	[1=Y 0=N]	PRO4
Cumulative Yield	79.6%		CYLD4
Effective Production Volume	1,256	/yr	ENUM4
Process Cycle Time	0.01	hrs/pc	CTIME4
Runtime for One Station	1%		RTIME4
Number of Parallel Stations	1.00		NSTAT4
Energy Requirement	0	kWh/pc	ENERGY4
Building Space/Station	100	sq ft	SPACE4
Installed Equipment Cost	$8,100	/sta	IEQUIP4
Auxiliary Equipment Cost	$900	/sta	AEQUIP4
Equipment Annuity	$2,295	/yr	EINT4
Tooling Annuity	$0	/yr	TINT4
Building Annuity	$1,158	/yr	BINT4
Working Annuity	$52,725	/yr	WINT4

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MICROWAVE CVD TCM: LAPPING
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$732.33	$732,333	66.4%	
Direct Labor Cost	$148.06	$148,060	13.4%	
Utility Cost	$5.84	$5,845	0.5%	
FIXED COST ELEMENTS				
Equipment Cost	$14.33	$14,327	1.3%	$71,634
Tooling Cost	$75.11	$75,110	6.8%	$375,550
Building Cost	$8.00	$8,000	0.7%	$160,000
Maintenance Cost	$18.53	$18,531	1.7%	
Overhead Labor Cost	$50.00	$50,000	4.5%	
Cost of Capital	$51.06	$51,065	4.6%	
TOTAL FABRICATION COST	$1,103.27	$1,103,269	100.0%	$607,184

INTERMEDIATE CALCULATIONS			
Process In Use	1.00	[1=Y 0=N]	PRO5
Cumulative Yield	80.4%		CYLD5
Effective Production Volume	1,244	/yr	ENUM5
Thickness of Material Lapped	111.11	um	HLAP5
Setup Time	1.33	hrs/batch	CTIME5A
Lapping Time	111.11	hrs/batch	CTIME5B
Runtime for One Station	381%		RTIME5
Number of Parallel Stations	4.00		NSTAT5
Lapping Plate Cost	$869	/ea	PLA5
Lapping Plate Life	14	pcs	WHEEL5
Number of Plates Required	432.00		PLAT5
Lapping Slurry Consumption	11.11	l/pc	GRIT5
Machine Power	4.2	kW	PWR5
Energy Requirement	94	kWh/pc	ENERGY5
Machine Cost	$11,939	/sta	MCH5
Building Space/Station	400	sq ft	SPACE5
Installed Equipment Cost	$16,118	/sta	IEQUIP5
Auxiliary Equipment Cost	$1,791	/sta	AEQUIP5
Equipment Annuity	$18,264	/yr	EINT5
Tooling Annuity	$95,752	/yr	TINT5
Building Annuity	$18,528	/yr	BINT5
Working Annuity	$970,725	/yr	WINT5

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MICROWAVE CVD TCM: HOT IRON POLISHING
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	#DIV/0!	
Direct Labor Cost	$0.00	$0	#DIV/0!	
Utility Cost	$0.00	$0	#DIV/0!	
FIXED COST ELEMENTS				
Equipment Cost	$0.00	$0	#DIV/0!	$0
Tooling Cost	$0.00	$0	#DIV/0!	$0
Building Cost	$0.00	$0	#DIV/0!	$0
Maintenance Cost	$0.00	$0	#DIV/0!	
Overhead Labor Cost	$0.00	$0	#DIV/0!	
Cost of Capital	$0.00	$0	#DIV/0!	
TOTAL FABRICATION COST	$0.00	$0	#DIV/0!	$0

INTERMEDIATE CALCULATIONS			
Process In Use	0.00	[1=Y 0=N]	PRO6
Cumulative Yield	89.3%		CYLD6
Effective Production Volume	1,119	/yr	ENUM6
Volume of Material Lapped	111.11	um	HLAP6
Setup Time	0.67	hrs/batch	CTIME6A
Lapping Time	22.22	hrs/batch	CTIME6B
Runtime for One Station	70%		RTIME6
Number of Parallel Stations	1.00		NSTAT6
Lapping Plate Cost	$784	/ea	PLA6
Lapping Plate Life	50	pcs	WHEEL6
Number of Plates Required	112.00		PLAT6
Machine Power	45.8	kW	PWR6
Energy Requirement	204	kWh/pc	ENERGY6
Machine Cost	$21,939	/sta	MCH6
Building Space/Station	400	sq ft	SPACE6
Installed Equipment Cost	$29,618	/sta	IEQUIP6
Auxiliary Equipment Cost	$3,291	/sta	AEQUIP6
Equipment Annuity	$0	/yr	EINT6
Tooling Annuity	$0	/yr	TINT6
Building Annuity	$0	/yr	BINT6
Working Annuity	$0	/yr	WINT6

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MICROWAVE CVD TCM: OXYGEN PLASMA POLISHING
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	#DIV/0!	
Direct Labor Cost	$0.00	$0	#DIV/0!	
Utility Cost	$0.00	$0	#DIV/0!	
FIXED COST ELEMENTS				
Equipment Cost	$0.00	$0	#DIV/0!	$0
Tooling Cost	$0.00	$0	#DIV/0!	$0
Building Cost	$0.00	$0	#DIV/0!	$0
Maintenance Cost	$0.00	$0	#DIV/0!	
Overhead Labor Cost	$0.00	$0	#DIV/0!	
Cost of Capital	$0.00	$0	#DIV/0!	
TOTAL FABRICATION COST	$0.00	$0	#DIV/0!	$0

INTERMEDIATE CALCULATIONS

Process In Use	0.00	[1=Y 0=N]	PRO7	
Cumulative Yield	89.3%		CYLD7	
Effective Production Volume	1,119	/yr	ENUM7	
Thickness of Material Lapped	111.11	um	HLAP7	
Polishing Time	33.67	hrs/batch	CTIME7A	
Load/Unload Time	0.00	min	LTIME7	
Total Process Cycle Time	34.34	hrs/pc	CTIME7	
Runtime for One Station	523%		RTIME7	
Number of Parallel Stations	6.00		NSTAT7	
	Consumption (SCM/pc)	Cost ($/pc)		
Oxygen Consumption	1.03	$2.31	GASA7	COSTA7
Argon Consumption	0.00	$0.00	GASB7	COSTB7
Other Gas Consumption	0.00	$0.00	GASC7	COSTC7
Energy Requirement	343	kWh/pc	ENERGY7	
Building Space/Station	400	sq ft	SPACE7	
Installed Equipment Cost	$405,000	/sta	IEQUIP7	
Auxiliary Equipment Cost	$45,000	/sta	AEQUIP7	
Equipment Annuity	$0	/yr	EINT7	
Tooling Annuity	$0	/yr	TINT7	
Building Annuity	$0	/yr	BINT7	
Working Annuity	$0	/yr	WINT7	

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MICROWAVE CVD TCM: OXYGEN ION MILLING
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	#DIV/0!	
Direct Labor Cost	$0.00	$0	#DIV/0!	
Utility Cost	$0.00	$0	#DIV/0!	
FIXED COST ELEMENTS				
Equipment Cost	$0.00	$0	#DIV/0!	$0
Tooling Cost	$0.00	$0	#DIV/0!	$0
Building Cost	$0.00	$0	#DIV/0!	$0
Maintenance Cost	$0.00	$0	#DIV/0!	
Overhead Labor Cost	$0.00	$0	#DIV/0!	
Cost of Capital	$0.00	$0	#DIV/0!	
TOTAL FABRICATION COST	$0.00	$0	#DIV/0!	$0

INTERMEDIATE CALCULATIONS

Process In Use	0.00	[1=Y 0=N]	PRO8	
Cumulative Yield	89.3%		CYLD8	
Effective Production Volume	1,119	/yr	ENUM8	
Thickness of Material Lapped	111.11	um	HLAP8	
Polishing Time	462.96	hrs/batch	CTIME8A	
Load/Unload Time	0.00	min	LTIME8	
Total Process Cycle Time	154.57	hrs/pc	CTIME8	
Runtime for One Station	785%		RTIME8	
Number of Parallel Stations	8.00		NSTAT8	
	Consumption (SCM/pc)	Cost ($/pc)		
Oxygen Consumption	0.09	$0.21	GASA8	COSTA8
Argon Consumption	0.00	$0.00	GASB8	COSTB8
Other Gas Consumption	0.00	$0.00	GASC8	COSTC8
Energy Requirement	155	kWh/pc	ENERGY8	
Building Space/Station	400	sq ft	SPACE8	
Ion Source Life	19	pcs	SLIFE8	
Number of Sources Required	289.00		SNUM5	
Installed Equipment Cost	$675,000	/sta	IEQUIP8	
Auxiliary Equipment Cost	$75,000	/sta	AEQUIP8	
Equipment Annuity	$0	/yr	EINT8	
Tooling Annuity	$0	/yr	TINT8	
Building Annuity	$0	/yr	BINT8	
Working Annuity	$0	/yr	WINT8	

MICROWAVE CVD TCM: METALLIZATION - SPUTTERING
IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$1.52	$1,520	1.2%	
Direct Labor Cost	$0.24	$242	0.2%	
Utility Cost	$0.02	$16	0.0%	
FIXED COST ELEMENTS				
Equipment Cost	$67.65	$67,655	52.6%	$338,274
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$2.00	$2,000	1.6%	$40,000
Maintenance Cost	$30.26	$30,262	23.5%	
Overhead Labor Cost	$5.00	$5,000	3.9%	
Cost of Capital	$21.84	$21,844	17.0%	
TOTAL FABRICATION COST	$128.54	$128,539	100.0%	$378,274

INTERMEDIATE CALCULATIONS

Process In Use	1.00	[1=Y 0=N]	PRO9
Cumulative Yield	89.3%		CYLD9
Effective Production Volume	1,119	/yr	ENUM9

Metal Coating	Consumption (g/pc)	Cost ($/pc)	'ep.Time (min)
Titanium	0.01	$0.02	4.17
Platinum	0.04	$0.74	2.67
Gold	0.04	$0.60	1.45

Metallization Thickness	0.30	um	THK9
Metallization Time	8.28	min	SPUT9
Preheat Time	9.00	min	PREHT9
Load/Unload Time	0.00	min	LTIME9
Total Process Cycle Time	0.10	hrs/pc	CTIME9
Runtime for One Station	5%		RTIME9
Number of Parallel Stations	1.00		NSTAT9
Wafer Capacity per Station	547.24	cm^2	CAP9
Machine Cost	$225,516	/sta	MCH9
Energy Requirement	0.288	kWh/pc	ENERGY9
Building Space/Station	400	sq ft	SPACE9
Installed Equipment Cost	$304,447	/sta	IEQUIP9
Auxiliary Equipment Cost	$33,827	/sta	AEQUIP9
Equipment Annuity	$86,248	/yr	EINT9
Tooling Annuity	$0	/yr	TINT9
Building Annuity	$4,632	/yr	BINT9
Working Annuity	$37,659	/yr	WINT9

MICROWAVE CVD TCM: METALLIZATION - EVAPORATION
IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	#DIV/0!	
Direct Labor Cost	$0.00	$0	#DIV/0!	
Utility Cost	$0.00	$0	#DIV/0!	
FIXED COST ELEMENTS				
Equipment Cost	$0.00	$0	#DIV/0!	$0
Tooling Cost	$0.00	$0	#DIV/0!	$0
Building Cost	$0.00	$0	#DIV/0!	$0
Maintenance Cost	$0.00	$0	#DIV/0!	
Overhead Labor Cost	$0.00	$0	#DIV/0!	
Cost of Capital	$0.00	$0	#DIV/0!	
TOTAL FABRICATION COST	$0.00	$0	#DIV/0!	$0

INTERMEDIATE CALCULATIONS

Process In Use	0.00	[1=Y 0=N]	PRO10
Cumulative Yield	90.3%		CYLD10
Effective Production Volume	1,108	/yr	ENUM10

Metal Coating	Consumption (g/pc)	Cost ($/pc)	)ep.Time (min)
Titanium	0.01	$0.04	0.02
Platinum	0.04	$0.73	0.02
Gold	0.04	$0.51	0.02

Metallization Thickness	0.30	um	THK10
Metallization Time	0.06	min	EVAP10
Preheat Time	21.00	min	PREHT10
Load/Unload Time	0.00	min	LTIME10
Total Process Cycle Time	0.07	hrs/pc	CTIME10
Runtime for One Station	3%		RTIME10
Number of Parallel Stations	1.00		NSTAT10
Wafer Capacity per Station	141.37	cm^2	CAP10
Machine Cost	$141,904	/sta	MCH10
Energy Requirement	0.491	kWh/pc	ENERGY10
Building Space/Station	400	sq ft	SPACE10
Installed Equipment Cost	$191,570	/sta	IEQUIP10
Auxiliary Equipment Cost	$21,286	/sta	AEQUIP10
Equipment Annuity	$0	/yr	EINT10
Tooling Annuity	$0	/yr	TINT10
Building Annuity	$0	/yr	BINT10
Working Annuity	$0	/yr	WINT10

MICROWAVE CVD TCM: INSPECTION - MICROSCOPY
IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	0.0%	
Direct Labor Cost	$5.25	$5,249	6.4%	
Utility Cost	$0.00	$1	0.0%	
FIXED COST ELEMENTS				
Equipment Cost	$15.00	$15,000	18.2%	$75,000
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$0.25	$250	0.3%	$5,000
Maintenance Cost	$6.40	$6,400	7.8%	
Overhead Labor Cost	$50.00	$50,000	60.7%	
Cost of Capital	$5.48	$5,482	6.7%	
TOTAL FABRICATION COST	$82.38	$82,382	100.0%	$80,000

INTERMEDIATE CALCULATIONS			
Process In Use	1.00	[1=Y 0=N]	PRO11
Cumulative Yield	90.3%		CYLD11
Effective Production Volume	1,108	/yr	ENUM11
Process Cycle Time	0.25	hrs	CTIME11
Runtime for One Station	10%		RTIME11
Number of Parallel Stations	1.00		NSTAT11
Energy Requirement	0	kWh/pc	ENERGY11
Building Space/Station	50	sq ft	SPACE11
Installed Equipment Cost	$67,500	/sta	IEQUIP11
Auxiliary Equipment Cost	$7,500	/sta	AEQUIP11
Equipment Annuity	$19,122	/yr	EINT11
Tooling Annuity	$0	/yr	TINT11
Building Annuity	$579	/yr	BINT11
Working Annuity	$62,680	/yr	WINT11

MICROWAVE CVD TCM: INSPECTION - THERMAL CONDUCTIVITY
IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	0.0%	
Direct Labor Cost	$4.99	$4,986	6.1%	
Utility Cost	$0.00	$1	0.0%	
FIXED COST ELEMENTS				
Equipment Cost	$15.00	$15,000	18.3%	$75,000
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$0.25	$250	0.3%	$5,000
Maintenance Cost	$6.40	$6,400	7.8%	
Overhead Labor Cost	$50.00	$50,000	60.9%	
Cost of Capital	$5.48	$5,477	6.7%	
TOTAL FABRICATION COST	$82.11	$82,115	100.0%	$80,000

INTERMEDIATE CALCULATIONS			
Process In Use	1.00	[1=Y 0=N]	PRO12
Cumulative Yield	95.0%		CYLD12
Effective Production Volume	1,053	/yr	ENUM12
Process Cycle Time	0.25	hrs	CTIME12
Runtime for One Station	10%		RTIME12
Number of Parallel Stations	1.00		NSTAT12
Energy Requirement	0	kWh/pc	ENERGY12
Building Space/Station	50	sq ft	SPACE12
Installed Equipment Cost	$67,500	/sta	IEQUIP12
Auxiliary Equipment Cost	$7,500	/sta	AEQUIP12
Equipment Annuity	$19,122	/yr	EINT12
Tooling Annuity	$0	/yr	TINT12
Building Annuity	$579	/yr	BINT12
Working Annuity	$62,413	/yr	WINT12

MICROWAVE CVD TCM: COST SUMMARY

IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$879.05	$879,047	12.0%	
Direct Labor Cost	$292.42	$292,417	4.0%	
Utility Cost	$399.36	$399,362	5.4%	
FIXED COST ELEMENTS				
Equipment Cost	$2,877.14	$2,877,145	39.2%	$14,385,724
Tooling Cost	$412.80	$412,805	5.6%	$2,064,023
Building Cost	$22.25	$22,250	0.3%	$445,000
Maintenance Cost	$1,186.46	$1,186,458	16.2%	
Overhead Labor Cost	$280.00	$280,000	3.8%	
Cost of Capital	$984.20	$984,196	13.4%	
TOTAL FABRICATION COST	$7,333.68	$7,333,680	100.0%	$16,894,747

SUMMARY INFORMATION

Part Name	6 in. substrate	
Total Direct Laborers	6.25	/shift
Total Floor Space	6,750	sqft
Total Capital Investment	$16.9	MM
Area Cost	$40.20	/sqcm
Cost Per Carat	$22.91	/ct

Operation	Equipment	Material	Labor	Other
Surface Preparation	$20	$3	$26	$19
Deposition	$2,744	$142	$183	$2,745
Etching	$0	$0	$0	$0
Laser Trimming	$2	$0	$50	$4
Lapping	$14	$732	$198	$159
Hot Iron Polishing	$0	$0	$0	$0
Oxygen Plasma Polishing	$0	$0	$0	$0
Oxygen Ion Beam Polishing	$0	$0	$0	$0
Metallization - Sputtering	$68	$2	$5	$54
Metallization - Evaporation	$0	$0	$0	$0
Inspect - Microscopy	$15	$0	$55	$12
Inspect - Thermal Cond'vity	$15	$0	$55	$12
Total	$2,877	$879	$572	$3,005
Total =	$7,334			

Appendix C

MICROWAVE CVD DIAMOND TECHNICAL COST MODEL
IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

Revision Date: 10/18/93

PRODUCT SPECIFICATIONS

Part Name	6 in. substrate		NAME
Finished Wafer Thickness	1,000	um	THIK
Annual Production Volume	1	(000/yr)	NUM
Length of Production Run	5	yrs	PLIFE

PROCESS RELATED FACTORS - SURFACE PREPARATION

Process In Use?	1.00	[1=Y 0=N]	USE1
Dedicated Investment	1.00	[1=Y 0=N]	DED1
Process Yield	95.0%		YLD1
Average Equipment Downtime	20.0%		DOWN1
Direct Laborers Per Station	0.50		NLAB1
Substrate Material	2	[menu #]	MATL1
Pieces Per Batch	20.00	pcs/batch	PCS1
Process Time	60.00	min/batch	PTIME1
Building Space Requirement	250	sqft/sta	FLR1

PROCESS RELATED FACTORS - DEPOSITION

Process In Use?	1.00	[1=Y 0=N]	USE2	
Dedicated Investment	0.00	[1=Y 0=N]	DED2	
Process Yield	90.0%		YLD2	
Average Equipment Downtime	15.0%		DOWN2	
Direct Laborers	0.20	/sta	NLAB2	
Gas Temperature (>1000K)	3,000	K	GTEMP2	
Substrate Temperature	1,200	K	STEMP2	
Reactor Pressure	110.0	torr	PRES2	
Recombine Coef. (gammaH)	0.10		HRECOMB2	
Plasma Ball Skew Factor (f)	3.00	(2=sym.)	SKEW2	
Hydrogen Concentration Exp	2.00		N=2	N=1
Diamond Quality Factor (Z)	1.42E-19	??????!	9E-20	7.76E-11
Diamond Density	3.52	g/cc	DENS	
Ideal Gas Constant (R)	62,358	c torr/K mol	IDLGAS2A	
Ideal Gas Constant 2 (R)	8.31	J / mol K	IDLGAS2B	

NASA Enthalpy Constants

	H2	H		
a1	2.99E+00	2.50E+00	H2EN2A	HEN2A
a2	7.00E-04	0.00E+00	H2EN2B	HEN2B
a3	-5.63E-08	0.00E+00	H2EN2C	HEN2C
a4	-9.23E-12	0.00E+00	H2EN2D	HEN2D
a5	1.58E-15	0.00E+00	H2EN2E	HEN2E
a6	-8.35E+02	2.55E+04	H2EN2F	HEN2F
a7	-1.36	-0.46	H2EN2G	HEN2G
MW	2.02	1.01	H2MW	HMW
	Menu #	vol%		

MICROWAVE CVD DIAMOND TECHNICAL COST MODEL
IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

GAS DATABASE

#	Gas	Source	Purity	Price $/SCM	No. of Carbons	Liq Gas	Tank gal	Price Update
0	None			$0.00	0.00	0.00		
1	Liq Hydrogen	Airco	99.998%	$0.34	0.00	1.00	6000	1/93
2	Liq Hydrogen	Airco	99.998%	$0.32	0.00	1.00	11000	1/93
3	Liq Hydrogen	Airco	99.998%	$0.30	0.00	1.00	20000	1/93
4	Liq Argon	Airco	99.998%	$1.41	0 00	1.00	3000	1/93
5	Liq Argon	Airco	99.998%	$1.32	0.00	1.00	6000	1/93
6	Liq Argon	Airco	99.998%	$1.29	0.00	1.00	11000	1/93
7	Hydrogen	MG Ind.	99.9999%	$29.86	0.00	0.00		1/93
8	Hydrogen	MG Ind.	99.9996%	$40.61	0.00	0.00		1/93
9	Hydrogen	MG Ind.	99.999%	$10.28	0.00	0.00		1/93
10	Hydrogen	Air Prod.	99.95%	$1.59	0.00	0.00		1/93
11	Argon	MG Ind.	99.9999%	$33.09	0.00	0.00		1/93
12	Argon	Air Prod.	99.9997%	$37.33	0.00	0.00		1/93
13	Argon	Air Prod.	99.999%	$11.74	0.00	0.00		1/93
14	Argon	Air Prod.	99.997%	$2.03	0.00	0.00		1/93
15	Methane	Air Prod.	99.99%	$21.99	1.00	0.00		1/93
16	Methane	Air Prod.	99%	$13.76	1.00	0.00		1/93
17	Methane	Air Prod.	93%	$4.93	1.00	0.00		1/93
18	Acetylene	Air Prod.	99.6%	$6.80	2.00	0.00		1/93
19	Acetylene	Air Prod.	98%	$5.85	2.00	0.00		1/93
20	Helium	Air Prod.	99.9995%	$15.90	0.00	0.00		1/93
21	Helium	Air Prod.	99.995%	$4.77	0.00	0.00		1/93
22	Nitrogen	Air Prod.	99.9996%	$45.50	0.00	0.00		1/93
23	Nitrogen	MG Ind.	99.999%	$9.23	0.00	0.00		1/93
24	Nitrogen	Air Prod.	99.998%	$1.24	0.00	0.00		1/93
25	Oxygen	Air Prod.	99.998%	$2.00	0.00	0.00		1/93
26								

SUBSTRATE DATABASE

#	Substrate	Source	Price Exp.	Price Coef.	Price Const.	Etch um/min	Life use#	Price Update
0	None		0.000	0.00	0	1.00	1.00	
1	Silicon	Si-Tech	4.335	0.00	2.81	#####	1	1/93
2	Molybdenum	logies Corp	2.000	0.34	11.17	#####	46.00	1/93
3	Tungsten	logies Corp	1.366	12.97	-80.44	#####	46.00	1/93
4								

TARGET DATABASE

#	Metal	Vendor	Price $/g	Dep.Rt. A/kWm	Density g/cc	Price Update
0	None		$0	#########	1.00	
1	Titanium	Tosoh	$1.90	80.00	4.51	1/93

Hydrogen	9	88.7%	GASA VOLA
Carbon Containing Gas	16	10.0%	GASB VOLB
Carrier Gas	0	0.0%	GASC VOLC
Other Gas	25	1.3%	GASD VOLD
		100.0%	

Hydrogen Recycle Rate	0.0%		RECYC	
Carrier Gas Recycle Rate	0.0%		RECYC2	
Gas Recycle Equipment Cost	$250,000	total	MCH2A	
Rated Microwave Power	75	kW	POW2	>5 kW
Microwave Coupling Eff.	98%		P2GEFF2	
Total Power Multiplier	200%		TPM2	
Carbon Capture Factor	10.0%		CCF2	
Machine Load/Unload Time	30.00	min/batch	PTIME2	
Available Deposition Time	8,640	hrs/yr	DAYHR2	
Microwave Tube Life	5000	hrs	LIFE2	
Coolant Temp. Rise	50.00	C	TEMP2	
Heat Capacity of Coolant	1.0	cal/g/C	CP2	
Building Space Requirement	400	sqft/sta	FLR2	

PROCESS RELATED FACTORS - ETCHING

Process In Use?	*0.00*	*[1=Y 0=N]*	*USE3*
Dedicated Investment	1.00	[1=Y 0=N]	DED3
Process Yield	99.0%		YLD3
Average Equipment Downtime	10.0%		DOWN3
Direct Laborers Per Station	1.00		NLAB3
Load/Unload and Rinse Time	30.00	min/batch	PTIME3
Pieces Per Batch	20.00		PCS3
Machine Cost	$6,000	/sta	MCH3
Etchant Cost	$70	/liter	ETCH3A
Etchant Disposal Cost	$30	/liter	ETCH3B
Machine Etchant Capacity	1.00	l/batch	CAP3
Machine Power	0.00	kW	POW3
Building Space Requirement	100	sqft/sta	FLR3

PROCESS RELATED FACTORS - LASER TRIMMING

Process In Use?	1.00	[1=Y 0=N]	USE4
Dedicated Investment	*1.00*	*[1=Y 0=N]*	*DED4*
Process Yield	99.0%		YLD4
Average Equipment Downtime	10.0%		DOWN4
Direct Laborers Per Station	1.00		NLAB4
Machine Cost	$6,000	/sta	MCH4
Trimming Rate	1.00	cm/s	RATE4
Machine Power	5.00	kW	POW4
Building Space Requirement	100	sqft/sta	FLR4

2	Platinum	Tosoh	$19.00	125.00	21.45	1/93
3	Gold	Tosoh	$17.00	230.00	19.32	1/93
4	Silver	Tosoh	$2.45	215.00	10.50	1/93
5	Copper	Tosoh	$1.15	210.00	8.96	1/93
6	Nickel	Tosoh	$0.95	30.00	8.91	1/93
7	Palladium	Tosoh	$8.45	210.00	12.02	1/93
8	Silicon	Tosoh	$0.80	15.00	2.33	1/93

EVAPORATION DATABASE

#	Metal	Vendor	Price $/g	Dep.Rt. A/kWm	Density g/cc	Price Update
0	None		$0	#########	1.00	
1	Titanium	re Tech Inc	$4.40	9,520.00	4.51	1/93
2	Platinum	re Tech Inc	$18.59	6,428.57	21.45	1/93
3	Gold	re Tech Inc	$14.58	6,428.57	19.32	1/93
4	Silver	re Tech Inc	$3.12	215.00	10.50	1/93
5	Copper	re Tech Inc	$1.08	210.00	8.96	1/93
6	Nickel	re Tech Inc	$1.49	30.00	8.91	1/93
7	Palladium	re Tech Inc	$7.03	210.00	12.02	1/93
8	Silicon	re Tech Inc	$7.51	15.00	2.33	1/93

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PROCESS RELATED FACTORS - LAPPING

Process In Use?	1.00	[1=Y 0=N]	USE5
Dedicated Investment	1.00	[1=Y 0=N]	DED5
Process Yield	90.0%		YLD5
Average Equipment Downtime	15.0%		DOWN5
Direct Laborers Per Station	0.25		NLAB5
Lapped Material Removal	10.0%	by wgt	TLAP5
No of Lapping Steps	2.00		LAPS5
Pieces Per Batch	5.00		PCS5
Load/Unload and Clean Wafers	40.00	min/batch	PTIME5
Average Lapping Rate	1.0	um/hr	RATE5
Lapping Slurry Cost	$53	/liter	LAPSL5
Lapping Slurry Usage Rate	0.50	liter/hr	LAPR5
Lapping Plate Life	320.00	hrs	PLAL5
Available Lapping Time	8,640	hrs/yr	DAYHR5
Building Space Requirement	400	sqft/sta	FLR5

PROCESS RELATED FACTORS - INSPECTION - MICROSCOPY

Process In Use?	1.00	[1=Y 0=N]	USE6
Dedicated Investment	1.00	[1=Y 0=N]	DED6
Process Yield	95.0%		YLD6
Average Equipment Downtime	5.0%		DOWN6
Direct Laborers Per Station	1.00		NLAB6
Average Inspection Time	15.00	min/batch	PTIME6
Percent Inspection	100%		INSP6
Machine Cost	$50,000	/sta	MCH6
Machine Power	0.10	kW	POW6
Building Space Requirement	50	sqft/sta	FLR6

PROCESS RELATED FACTORS - INSPECTION - THERMAL CONDUCTIVITY

Process In Use?	1.00	[1=Y 0=N]	USE7
Dedicated Investment	1.00	[1=Y 0=N]	DED7
Process Yield	95.0%		YLD7
Average Equipment Downtime	5.0%		DOWN7
Direct Laborers Per Station	1.00		NLAB7
Average Inspection Time	15.00	min/batch	PTIME7
Percent Inspection	100%		INSP7
Machine Cost	$50,000	/sta	MCH7
Machine Power	0.10	kW	POW7
Building Space Requirement	50	sqft/sta	FLR7

OPTIONAL INPUTS

	override	estimate		
Surface Preparation				
Machine Cost	$0	$65,774	/sta	OMCH1
Machine Power	0.0	19.2	kW	OPOW1
Deposition				
Plasma Ball Area	0.00	633.19	sq cm	OBAREA2

Plasma Ball Height	0.00	7.10	cm	OBGHT2
Deposition Diameter	0.00	25.8	cm	ODDIAM2
Deposition Rate	0.00	2.35	g/hr	ODRATE2
Deposition Equipment Cost	$0	$688	k$/sta	OMCH2
Microwave Tube Cost	$4,500	$4,500	/sta	OTUBE2
Etching				
Process Cycle Time	0.00	0.03	hrs	OCTIME3
Chemical Requirement	$0	$5.00	/pc	OCHEM3
Laser Trimming				
Process Cycle Time	0.00	0.02	hrs	OCTIME4
Lapping				
Lapping Time	0.00	111.11	hrs	OCTIME5
Lapping Plate Cost	$0	$869	/ea	OWHEEL5
Lapping Machine Cost	$0	$11,939	/sta	OMCH5
Lapping Machine Power	0.00	4.2	kW	OPWR5

EXOGENOUS COST FACTORS

Direct Wages	$13.33	/hr	WAGE	
Indirect Salary	$50,000	/yr	SALARY	* exc. dep. & lap
Indirect:Direct Labor Ratio	1.00		ILAB	
Benefits on Wage and Salary	35.0%		BENI	
Working Days per Year	360.00		DAYS	
Working Hours per Day (*)	8.00	/hr	HRS	
Capital Recovery Rate	10%		CRR	
Capital Recovery Period	5.00	yrs	ELIFE	
Building Recovery Life	20.00	yrs	BLIFE	
Working Capital Period	3.00	months	WCP	
Price of Electricity	$0.050	/kWh	ELEC	
Price of Natural Gas	$6.50	/MBTU	GAS	
Price of Building Space	$100	/sqft	PBLD	
Price of Cooling Water	$0.03	/100 gal	WATER	
Auxiliary Equipment Cost	15.0%		AUX	
Equipment Installation Cost	35.0%		INST	
Maintenance Cost	8.0%		MNT	

REGRESSION CONSTANTS, COEFFICIENTS, AND EXPONENTS

-Surface Preparation-		
Machine Cost Constant	1,334	MCH1A
Machine Cost Capacity Coef	3,222	MCH1B
Machine Power Constant	-0.75	PWR1A
Machine Power Capacity Coef	1.00	PWR1B
-Deposition-		
sma Ball Diam Power Exponent	0.38	BDIAM2X
Ball Diam Power Coefficient	5.01	BDIAM2Y
Plasma Ball Diam Constant	2.54	BDIAM2Z
Plasma Ball Area:Height	4.00	BAHRAT2
Machine Cost Power Coef	4,658	MCH2Y
Machine Cost Power Exponent	1.00	MCH2Z
Machine Cost Power Constant	338,896	MCH2X
Tube Cost Constant	1724	TUBE2Y

Tube Cost Coef	97.01	TUBE22
Tank 1 $ Capacity Constant	1,175	TANK2A
Tank 1 $ Capacity Coef	0.165	TANK2B
Tank 2 $ Capacity Constant	370.00	TANK2X
Tank 2 $ Capacity Coef	0.03	TANK2Y
-Etching-		
-Lapping-		
Machine Cost Constant	2,719	MCH5A
Machine Cost Capacity Coef	1,844	MCH5B
Machine Power Constant	-0.75	PWR5A
Machine Power Capacity Coef	1.00	PWR5B
Tool Cost Constant	771.00	TOOL5A
Tool Cost Capacity Coef	0.92	TOOL5B
Tool Cost Capacity Exponent	2.90	TOOL5C

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MICROWAVE CVD TCM: SURFACE PREPARATION
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$7.45	$7,453	10.4%	
Direct Labor Cost	$0.82	$818	1.1%	
Utility Cost	$0.07	$70	0.1%	
FIXED COST ELEMENTS				
Equipment Cost	$19.73	$19,732	27.4%	$98,661
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$1.25	$1,250	1.7%	$25,000
Maintenance Cost	$9.89	$9,893	13.7%	
Overhead Labor Cost	$25.00	$25,000	34.7%	
Cost of Capital	$7.79	$7,790	10.8%	
TOTAL FABRICATION COST	$72.01	$72,007	100.0%	$123,661

INTERMEDIATE CALCULATIONS

Process In Use	1.00	[1=Y 0=N]	PRO1
Cummulative Yield	68.8%		CYLD1
Effective Production Volume	1,454	/yr	ENUM1
Substrate Area	525.0	sq cm	AREA1
New Substrate Cost	$235.72	/pc	SUB1
Substrate Useful Life	46.00	cycle	LIFE1
Process Cycle Time	3	min/pc	CTIME1
Runtime for One Station	3%		RTIME1
Number of Parallel Stations	1.00		NSTAT1
Energy Requirement	0.959	kWh/pc	ENERGY1
Building Space/Station	250	sqft	SPACE1
Machine Cost	$65,774	/sta	MCH1
Machine Power	19.2	kW	POW1
Installed Equipment Cost	$88,795	/sta	IEQUIP1
Auxiliary Equipment Cost	$9,866	/sta	AEQUIP1
Equipment Annuity	$25,155	/yr	EINT1
Tooling Annuity	$0	/yr	TINT1
Building Annuity	$2,895	/yr	BINT1
Working Annuity	$43,957	/yr	WINT1

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MICROWAVE CVD TCM: DEPOSITION
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$608.16	$608,163	7.4%	
Direct Labor Cost	$514.93	$514,926	6.3%	
Utility Cost	$919.02	$919,021	11.2%	
FIXED COST ELEMENTS				
Equipment Cost	$3,418.17	$3,418,169	41.6%	$17,550,273
Tooling Cost	$74.80	$74,800	0.9%	$374,000
Building Cost	$33.11	$33,110	0.4%	$680,000
Maintenance Cost	$1,420.24	$1,420,244	17.3%	
Overhead Labor Cost	$165.55	$165,550	2.0%	
Cost of Capital	$1,064.15	$1,064,154	12.9%	
TOTAL FABRICATION COST	$8,218.14	$8,218,137	100.0%	$18,604,273

INTERMEDIATE CALCULATIONS

Process In Use	1.00	[1=Y 0=N]	PRO2
Cummulative Yield	72.4%		CYLD2
Effective Production Volume	1,382	/yr	ENUM2
Delivered Power	73.5	kW	EPOW2

HYDROGEN DIFFUSION CALCULATIONS

	H2	H·	
Enthalpy Per Unit Mass	44,019	271,987	J/g
Molar Enthalpy	88,734	274,136	J/mol
Molar Entropy	202.79	162.59	J/K mol
Molar Heat Capacity (Cp)	37.11	20.79	J/K mol

Heat of Reaction (H2==>2H·)	459,538	J/mol	HTRXN2
Plasma Ball Diameter	28.39	cm	BDIAM2
Plasma Ball Area	633.19	sq cm	BAREA2
Plasma Ball Half-Height	7.10	cm	BGHT2
Volume of Plasma	13,484	cc	BVOL2
Deposition Diameter	25.85	sq cm	DDIAM2
Mean H· Thermal Speed	502,063	cm/s	HSPEED2
H· Generation Rate	1.19E-05	mol/s/cc	HGEN2
H· Conc. at Substrate	1.34E-09	mol/cc	HCONC2

DEPOSITION RATE CALCULATIONS

Mass of Diamond Deposited	205.32	g	MASS2
Mass Deposition Rate	2.3	g/hr	MASDEP2
Linear Deposition Rate	12.7	µ/hr	LINDEP2
Deposition Time	87.49	hrs	CTIMEB2
Machine Setup Time	0.50	hrs	CTIMEA2

Runtime for One Station	1655%		RTIME2	
Number of Parallel Stations	16.55		NSTAT2	
Total Carbon Gas Volume	4.18	SCM	CARGAS2	
Total Gas Volume	42	SCM	TVOL2	
Total Gas Flow Rate	7,970	sccm	FLOWR2	
	Consumption (SCM/pc)	Cost ($/pc)		
Hydrogen Consumption	37.11	$527.12	GASA2	COSTA2
Carbon Gas Consumption	4.18	$79.54	GASB2	COSTB2
Carrier Gas Consumption	0.00	$0.00	GASC2	COSTC2
Other Gas Consumption	0.54	$1.50	GASD2	COSTD2
Energy Requirement	13,123	kWh/pc	ENERGY2	
Physical Tube Life	0.68	years	TLIFE2	
Number of Tubes per Station	8.00		NTUBE2	
New Microwave Tube Cost	$4,500	/tube	TUBE2A	
Reworked Microwave Tube Cost	$2,500	/tube	TUBE2B	
Cooling Water Flow Rate	5.7	gal/min	WATER2	
Cooling Water Requirement	29,803	gal/pc	COOL2	
Building Space/Station	400	sqft	SPACE2	
Recycle Equipment Cost	$0	/sta	REC2	
Liquid Hydrogen Tank Rental	$0	/mo/tank	HYD2	
Liq Carrier Gas Tank Rental	$0	/mo/tank	CAR2	
Gas Storage Equipment Rent	$0	/year	GTANK2	
Machine Cost	$688,246	/sta	MCH2B	
Installed Equipment Cost	$929,132	/sta	IEQUIP2	
Auxiliary Equipment Cost	$103,237	/sta	AEQUIP2	
Equipment Annuity	$4,357,560	/yr	EINT2	
Tooling Annuity	$95,357	/yr	TINT2	
Building Annuity	$76,684	/yr	BINT2	
Working Annuity	$3,688,536	/yr	WINT2	

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MICROWAVE CVD TCM: ETCHING
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	#VALUE!	
Direct Labor Cost	$0.00	$0	#VALUE!	
Utility Cost	$0.00	$0	#VALUE!	
FIXED COST ELEMENTS				
Equipment Cost	$0.00	$0	#VALUE!	$0
Tooling Cost	$0.00	$0	#VALUE!	$0
Building Cost	$0.00	$0	#VALUE!	$0
Maintenance Cost	$0.00	$0	#VALUE!	
Overhead Labor Cost	$0.00	$0	#VALUE!	
Cost of Capital	$0.00	$0	#VALUE!	
TOTAL FABRICATION COST	$0.00	$0	#VALUE!	$0

INTERMEDIATE CALCULATIONS			
Process In Use	0.00	[1=Y 0=N]	PRO3
Cumulative Yield	80.4%		CYLD3
Effective Production Volume	1,244	/yr	ENUM3
Total Etched Thickness	0	um	ETHIK3
Average Etchant Rate	10.00	um/min	ERATE3
Process Cycle Time	0.03	hrs/pc	CTIME3
Runtime for One Station	1%		RTIME3
Number of Parallel Stations	1.00		NSTAT3
Chemical Requirement	$5.00	/pc	CHEM3
Energy Requirement	0	kWh/pc	ENERGY3
Building Space/Station	100	sq ft	SPACE3
Installed Equipment Cost	$8,100	/sta	IEQUIP3
Auxiliary Equipment Cost	$900	/sta	AEQUIP3
Equipment Annuity	$0	/yr	EINT3
Tooling Annuity	$0	/yr	TINT3
Building Annuity	$0	/yr	BINT3
Working Annuity	$0	/yr	WINT3

MICROWAVE CVD TCM: .SER TRIMMING
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	0.0%	
Direct Labor Cost	$0.56	$561	1.0%	
Utility Cost	$0.01	$7	0.0%	
FIXED COST ELEMENTS				
Equipment Cost	$1.80	$1,800	3.2%	$9,000
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$0.50	$500	0.9%	$10,000
Maintenance Cost	$1.52	$1,520	2.7%	
Overhead Labor Cost	$50.00	$50,000	88.6%	
Cost of Capital	$2.02	$2,023	3.6%	
TOTAL FABRICATION COST	$56.41	$56,411	100.0%	$19,000

INTERMEDIATE CALCULATIONS			
Process In Use	1.00	[1=Y 0=N]	PRO4
Cumulative Yield	80.4%		CYLD4
Effective Production Volume	1,244	/yr	ENUM4
Process Cycle Time	0.02	hrs/pc	CTIME4
Runtime for One Station	1%		RTIME4
Number of Parallel Stations	1.00		NSTAT4
Energy Requirement	0	kWh/pc	ENERGY4
Building Space/Station	100	sq ft	SPACE4
Installed Equipment Cost	$8,100	/sta	IEQUIP4
Auxiliary Equipment Cost	$900	/sta	AEQUIP4
Equipment Annuity	$2,295	/yr	EINT4
Tooling Annuity	$0	/yr	TINT4
Building Annuity	$1,158	/yr	BINT4
Working Annuity	$52,959	/yr	WINT4

MICROWAVE CVD TCM: LAPPING
IBIS ASSOCIATES, INC. Copyright (c) 1991 v4.0

	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$725.01	$725,009	66.3%	
Direct Labor Cost	$146.58	$146,579	13.4%	
Utility Cost	$5.79	$5,786	0.5%	
FIXED COST ELEMENTS				
Equipment Cost	$14.33	$14,327	1.3%	$71,634
Tooling Cost	$74.41	$74,415	6.8%	$372,073
Building Cost	$8.00	$8,000	0.7%	$160,000
Maintenance Cost	$18.53	$18,531	1.7%	
Overhead Labor Cost	$50.00	$50,000	4.6%	
Cost of Capital	$50.73	$50,725	4.6%	
TOTAL FABRICATION COST	$1,093.37	$1,093,372	100.0%	$603,707

INTERMEDIATE CALCULATIONS

Process In Use	1.00	[1=Y 0=N]	PRO5
Cumulative Yield	81.2%		CYLD5
Effective Production Volume	1,231	/yr	ENUM5
Thickness of Material Lapped	111.11	um	HLAP5
Setup Time	1.33	hrs/batch	CTIME5A
Lapping Time	111.11	hrs/batch	CTIME5B
Runtime for One Station	377%		RTIME5
Number of Parallel Stations	4.00		NSTAT5
Lapping Plate Cost	$869	/ea	PLA5
Lapping Plate Life	14	pcs	WHEEL5
Number of Plates Required	428.00		PLAT5
Lapping Slurry Consumption	11.11	l/pc	GRIT5
Machine Power	4.2	kW	PWR5
Energy Requirement	94	kWh/pc	ENERGY5
Machine Cost	$11,939	/sta	MCH5
Building Space/Station	400	sq ft	SPACE5
Installed Equipment Cost	$16,118	/sta	IEQUIP5
Auxiliary Equipment Cost	$1,791	/sta	AEQUIP5
Equipment Annuity	$18,264	/yr	EINT5
Tooling Annuity	$94,865	/yr	TINT5
Building Annuity	$18,528	/yr	BINT5
Working Annuity	$961,714	/yr	WINT5

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MICROWAVE CVD TCM: INSPECTION - MICROSCOPY
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	0.0%	
Direct Labor Cost	$5.25	$5,249	6.4%	
Utility Cost	$0.00	$1	0.0%	
FIXED COST ELEMENTS				
Equipment Cost	$15.00	$15,000	18.2%	$75,000
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$0.25	$250	0.3%	$5,000
Maintenance Cost	$6.40	$6,400	7.8%	
Overhead Labor Cost	$50.00	$50,000	60.7%	
Cost of Capital	$5.48	$5,482	6.7%	
TOTAL FABRICATION COST	$82.38	$82,382	100.0%	$80,000

INTERMEDIATE CALCULATIONS

Process In Use	1.00	[1=Y 0=N]	PRO6
Cumulative Yield	90.3%		CYLD6
Effective Production Volume	1,108	/yr	ENUM6
Process Cycle Time	0.25	hrs	CTIME6
Runtime for One Station	10%		RTIME6
Number of Parallel Stations	1.00		NSTAT6
Energy Requirement	0	kWh/pc	ENERGY6
Building Space/Station	50	sq ft	SPACE6
Installed Equipment Cost	$67,500	/sta	IEQUIP6
Auxiliary Equipment Cost	$7,500	/sta	AEQUIP6
Equipment Annuity	$19,122	/yr	EINT6
Tooling Annuity	$0	/yr	TINT6
Building Annuity	$579	/yr	BINT6
Working Annuity	$62,680	/yr	WINT6

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MICROWAVE CVD TCM: INSPECTION - THERMAL CONDUCTIVITY
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$0.00	$0	0.0%	
Direct Labor Cost	$4.99	$4,986	6.1%	
Utility Cost	$0.00	$1	0.0%	
FIXED COST ELEMENTS				
Equipment Cost	$15.00	$15,000	18.3%	$75,000
Tooling Cost	$0.00	$0	0.0%	$0
Building Cost	$0.25	$250	0.3%	$5,000
Maintenance Cost	$6.40	$6,400	7.8%	
Overhead Labor Cost	$50.00	$50,000	60.9%	
Cost of Capital	$5.48	$5,477	6.7%	
TOTAL FABRICATION COST	$82.11	$82,115	100.0%	$80,000

INTERMEDIATE CALCULATIONS

Process In Use	1.00	[1=Y 0=N]	PRO7
Cumulative Yield	95.0%		CYLD7
Effective Production Volume	1,053	/yr	ENUM7
Process Cycle Time	0.25	hrs	CTIME7
Runtime for One Station	10%		RTIME7
Number of Parallel Stations	1.00		NSTAT7
Energy Requirement	0	kWh/pc	ENERGY7
Building Space/Station	50	sq ft	SPACE7
Installed Equipment Cost	$67,500	/sta	IEQUIP7
Auxiliary Equipment Cost	$7,500	/sta	AEQUIP7
Equipment Annuity	$19,122	/yr	EINT7
Tooling Annuity	$0	/yr	TINT7
Building Annuity	$579	/yr	BINT7
Working Annuity	$62,413	/yr	WINT7

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MICROWAVE CVD TCM: COST SUMMARY
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	per piece	per year	percent	investment
VARIABLE COST ELEMENTS				
Material Cost	$1,340.63	$1,340,626	13.9%	
Direct Labor Cost	$696.21	$673,119	7.2%	
Utility Cost	$924.89	$924,887	9.6%	
FIXED COST ELEMENTS				
Equipment Cost	$3,484.03	$3,484,028	36.2%	$17,879,568
Tooling Cost	$149.21	$149,215	1.5%	$746,073
Building Cost	$43.36	$43,360	0.5%	$885,000
Maintenance Cost	$1,462.99	$1,462,987	15.2%	
Overhead Labor Cost	$390.55	$390,550	4.1%	
Cost of Capital	$1,135.65	$1,135,652	11.8%	
TOTAL FABRICATION COST	$9,627.51	$9,604,423	100.0%	$19,510,641

SUMMARY INFORMATION

Part Name	6 in. substrate	
Total Direct Laborers	8.90	/shift
Total Floor Space	8,950	sqft
Total Capital Investment	$19.5	MM
Area Cost	$18.34	/sqcm
Cost Per Carat	$10.45	/ct

Operation	Equipment	Material	Labor	Other
Surface Preparation	$20	$7	$26	$19
Deposition	$3,418	$608	$680	$3,511
Etching	$0	$0	$0	$0
Laser Trimming	$2	$0	$51	$4
Lapping	$14	$725	$197	$157
Inspect - Microscopy	$15	$0	$55	$12
Inspect - Thermal Cond'vity	$15	$0	$55	$12
Total	$3,484	$1,341	######	$3,716
Total =	$9,604			

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